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EXPERIMENTAL INQUIRY

INTO THE CAUSE OF THE

PERMANENT COLOURS

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OPAKE BODIES.

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EDWARD HUSSEY DELAVAL, F.R.S.

Of the ROYAL SOCIETIES of UPSAL, and GOTTINGEN, of the
INSTITUTE of BOLOGNA, and of the LITERARY and
PHILOSOPHICAL SOCIETY of MANCHESTER.

Ars sine scientia esse non potest. CICERO.

WARRINGTON:

PRINTED BY W. EYRES.

MDCCLXXXV.

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AN EXPERIMENTAL INQUIRY
INTO THE CAUSE OF THE
PERMANENT COLOURS
OF
OPAQUE BODIES.

THE chief design of this inquiry is, to investigate the nature, origin, and cause, of the permanent colours of opaque bodies.

I was led to the pursuit of it, from a persuasion of its utility, to those interesting and elegant Arts, whose object is the preparation, and use, of colouring substances.

The discovery of this principle is the foundation, on which alone all the parts and materials of the knowledge, relative to those Arts, can be raised and supported.

It should be the office of experimental philosophy, to examine the powers and properties of all the materials, requisite to technical uses. Nor should its views be confined to the theories, which result from those researches, but directed to the practical application of them.

In proportion as the Principles of any Science are unknown or misconceived, the advancement of the Arts and Manufactures, which depend on them, must of course be impeded: for, without those guides, no addition or improvement can be attained, except such as arise from mere accidental observation.

But when scientific Principles are disclosed to the Artist, he becomes enabled to draw, from those original sources, an ample store of useful inventions, by which his Art is constantly enriched; and from thence considerable advantages may be derived. And thus the speculative Sciences, by their extension to practical purposes, become objects of great public utility.

The truth of this observation is, in no instance, more conspicuous, than when applied to the Science of Optics, and to the Arts and Manufactures, which are connected with, and dependent upon it. For, the invention and improvement of the several operations, which owe their rise to that Science, appear to have kept an equal pace with the philosophical discoveries, by which they were suggested: and their progress seems to have been constantly retarded, in proportion as the correspondent branches of the parent Science have remained in a state of deficiency or imperfection.

The experiments and observations, which have been made by means of Transparent Colourless Substances,

Substances, are very numerous, and the action and powers of such bodies, in reflecting and refracting light, have been, in a great measure, discovered and explained.

In consequence of those discoveries, optical instruments have been brought to a considerable degree of perfection.

It is further observable, that from the misconception of a single circumstance, in this department of the science, there arose an obstacle to the construction of telescopes, which the united efforts of artificers were unable to surmount, till the error was rectified.

This error, which had escaped even the penetration of Sir Isaac Newton, originated from a supposition, that the divergency of all the rays, which pass through any media, is constantly equal to their refraction.

The inaccuracy of this opinion was first observed by M. Euler, and the subject was afterwards attentively pursued by the Academicians Clairaut, Klingenshierna, Beguelin, Zeiher, and D'Alembert: but, we are indebted to M. Dollond, for the final discovery of the Principles, and their application to the construction of telescopes, superior to any which had ever been before produced.

In this happy instance, the genius of the Philosopher, and the hand of the Artist, were united in the same person.

I have thus briefly considered the present state of our knowledge, of the optical properties of Colourless Transparent Substances; and the condition and progress of the Arts which are subordinate to, and connected with them.

The industry and attention of philosophers has not hitherto, in any great degree, been exercised on the consideration of Permanently Coloured Bodies.

It will appear, in the course of this inquiry, that the disposition of such substances to exhibit their colours, has not been examined by experiments, which are the true and only means of discovering, and explaining, its cause. And it will be shewn, that the hypothetical opinions, which have been offered on this subject, are not supported by actual observations, and do not account for, or agree with, the phænomena.

From the imperfection of this branch of Optics, and from the influence which its defects exert on those Arts, whose improvement depends upon a clear and just conception of the nature, preparation, and use of colouring materials, it is not difficult to deduce the reason of the immaturity, and deficiency, under which they labour,

So far, indeed, are we from having advanced towards a state of perfection, that if we cast our views back to the remotest regions of Science, we shall find, from such a retrospect, that the
most

most ancient nations possessed an excellence in all those Arts, which the ablest moderns cannot dispute with them.

In a former work, I have shewn that the Art of Dying was cultivated in the remotest ages, in Phœnicia, Egypt, India, the land of Canaan, and other countries; and that they excelled even in the most difficult and elaborate branches of this art. They were also skilled in making artificial gems, and tinging glass, and enamel, with the brightest colours.

From the testimony of the earliest historians, we are informed of the high antiquity of the Art of Painting, in Egypt, and other countries which gave birth to the Arts and Sciences: and many beautiful remains of antiquity, which are still extant, are clear and lasting proofs of the great proficiency of those ancient nations in that Art.

Theophrastus, Pliny, and others, have enumerated the colours, employed in the various methods of antique painting.

These colours include almost all the pigments, which are employed by the moderns. Prussian Blue, which, with a few others, has been added, was discovered by an accidental mixture of the ingredients, which enter into the composition of it. Nor is it so durable as the blue paints, which were in use before its introduction.

Pliny informs us, that in his time Painting had greatly degenerated from its former state.

It is not my purpose in this brief review of the colouring arts, to advert to their condition at that period, as they had then fallen from their primitive excellence; nor to consider them in any other respect, than that which regards the beauty, and durability, of the colours, abstracted from any other circumstances whatsoever.

The paints, which Apelles used, were so bright, that he found it expedient to glaze his pictures, with a dusky varnish, that the vividness of the colours might not offend the sight.*

But notwithstanding the allowed merit of this celebrated painter, and of his cotemporaries, in the execution of their art, their colours were greatly surpassed, in variety, brightness, and permanency, in the works which had been perfected long before such arts were cultivated in Greece; and which, after so long a series of ages, still continue unimpaired, and probably will ever remain so, unless destroyed by violence.

I have selected the following passages, relative to this subject, from the authentic description

* *Inventa ejus et cæteris profuere in arte. Unum imitari nemo potuit, quod absoluta opera atramento illinebat ita tenui, ut idipsum repercussu claritates oculorum excitaret, custodiretque a pulvere et sordibus, ad manum intuenti demum appareret. Sed et tum ratione magna ne colorum claritas oculorum aciem offenderet, veluti per lapidem specularem intuentibus è longinquo.*

Plinii. L. XXXV. Cap. 10.

which

which Norden has given of the extensive and magnificent remains of Thebes, in the Upper Egypt, which was the capital of the Eastern World. That traveller, in a letter to the Baron de Stofsch, thus relates his observations.

“ I hope to get the author you tell me of, but
“ as he treats only of the paintings upon the cases
“ of the Mummies, he will be of no great use to
“ me in explaining those wonderful ones, that
“ I have seen upon an infinite number of ancient
“ buildings, or in giving the least idea of them.
“ Imagine to yourself, in the extent of an Italian
“ league, palaces with columns thirty-two French
“ feet in circumference, cased with sandy stones
“ cut in squares, and all over covered, within
“ and without, with paintings, representing the
“ worship of the deities of the country, the
“ ceremonies and customs of the inhabitants,
“ their manner of making war and sailing,
“ together with love devices intermixed. Con-
“ sider likewise, that the manner of painting is
“ so totally different from any thing in practice
“ at this time, as to make it necessary for me
“ to give you some slight idea of it. A painting
“ eighty feet high, and proportionably broad,
“ is divided into two ranges of gigantic figures
“ in bass relief, and covered with most exquisite
“ colours, suited to the drapery and naked parts
“ of the figure. But what is still more wonder-
“ ful is this, that the *azure, the yellow, the green,*
“ *and*

“and the other colours made use of, are as well
 “preserved, as if they had been laid on but yesterday,
 “and so strongly fixed to the stone, that I was never
 “able to separate them in the least degree. You
 “will ask me, whether the design is good and
 “has taste? yes, Sir, the whole is executed
 “with much greater exactness, than the idols
 “of granite which we both have seen in the
 “Capitol.”*

These further remarks are cited from the
 journal of the same author.† “We passed
 “afterwards

* Norden’s Travels in Egypt, by Templeman, p. 33.

† lb. vol. II. p. 75.

In confirmation, and as a farther explanation of these
 accounts, I shall here insert some extracts from Perry’s
 voyage to Upper Egypt, which abounds in descriptions
 and praises of the paintings, that adorn the temples and
 palaces of that splendid scene of antiquity.

|| “At Carnac (commonly called Luxor il Kadim, and
 “formerly a part of Thebes) we went ashore, and march-
 “ing along, with great avidity directly to it, we found
 “the most stately, magnificent and surprizing temple
 “that ever eye beheld: doubtless, it is impossible to
 “think, speak, or write of this edifice, without trans-
 “port or rapture; for its splendour, glory and magni-
 “ficence are such, as are truly unspeakable, and perhaps
 “inconceivable. The front of this portal from top to
 “bottom, on each side for a width of nine or ten feet,
 “and the whole inner side of the portal the same, are
 “all filled with the most beautiful figures in basso relievo,
 “and

|| A View of the Levant, by C. Perry, M.D. London. 1743. p. 341.

“ afterwards to the ruins, that are found on the
“ north side. There is no doubt but they are
“ the remains of the palace of Memnon.

“ The reader may there remark, letter C the
“ portico of a temple, capable of giving a great
“ idea of the Egyptian architecture.

“ The hieroglyphics are agreeable to the
“ sight, and when you are quite near, *their*
“ *colours have a charming effect.*

“ It is something surprizing to see how gold,
“ *ultra marine, and divers other colours, have pre-*
“ *served their lustre to the present age.*”

“ and hieroglyphics, and all these are *painted over in a*
“ *most curious and exquisite manner.*

“ This grand sumptuous portal, is no other than a
“ passage which leads from the first court or salon, into
“ a second. This salon, which is equimensurate with
“ the former, viz. one hundred paces wide, and sixty
“ deep, is perfectly crowded with pillars, like the former
“ as to shape and ornaments, only that these are larger,
“ being near twelve feet in diameter, and seventy-two feet
“ high: all these columns as well as the ceiling, roof and
“ walls of the apartment are quite covered or crowded
“ with figures in basso relievo, and hieroglyphics, *all*
“ *exquisitely beautiful, and finely painted all over—and which*
“ may seem very extraordinary, all these things *look as*
“ *fresh, splendid and glorious, after so many ages, as if they*
“ *were but just finished.*”

Diodorus Siculus, in his description of Thebes, mentions such gigantic figures, covered with the most beautiful colours, as well as the other kinds of paintings, which are still extant in the remains of that city.

Such

Such was the state of Painting in Egypt, above three thousand years ago. The other colouring arts were carried to a high degree of improvement, at an equally remote period.

We learn, from the concurrent testimony of both sacred and profane historians, that the countries, where these Arts originally flourished were antecedent, and superior to all others, in their diligent and successful observations of nature, and in the invention and culture of the Sciences.

These, undoubtedly, gave rise to the executive Arts, and opened a way to their advancement and perfection.

But, after a succession of several ages, both the theoretical knowledge, and the practical skill, of those nations, underwent a considerable decline, and shared the general desolation which had befallen, from civil disasters, and foreign invasions.

Those repositories of the Arts and Sciences had already far receded from their primeval condition, at the time that the ancient sages of Greece resorted to them, for instruction.

So that, although the researches of those travellers were repaid by the acquirement of some general physical truths, which had been traditionally preserved, they could not, by the most diligent inquiry, attain an insight into any of the progressive means of information, from which such truths had been deduced.

Nor

Nor were they enabled, on their return to their own country, to transfer to it the methods of executing those beautiful and magnificent works, which had been the objects of their admiration.

The moderns were not furnished with any adequate means of retrieving the Principles of ancient Science, till they began to avail themselves of experimental observations; and till academies were instituted, for the purpose of enabling them mutually to communicate their discoveries to each other.

The present age has produced many excellent philosophers, whose labours have been directed to inquiries, from whence great improvements must necessarily result to the Arts, and Operations, which are of the highest importance to the convenience and happiness of mankind.

I shall think myself fortunate, if the slight addition of my endeavours prove, in the least degree, conducive to that end.

In a former work, I have considered the Differences or Changes of Colour, in permanently coloured bodies, and have shewn that they are effected in the same manner, and according to the same law, which prevails in Transparent Colourless Substances.

By this means, the philosophical principle is established, and applied to the practical uses of several Arts: particularly to those of Dying, Painting,

ing, and such others as depend upon the knowledge, and management, of Colouring Materials.

The experiments, by which the cause of those changes of colours was investigated, consisted chiefly of various methods of uniting the Colouring Particles into larger, or dividing them into smaller, masses.

I shall now proceed to examine those properties of Permanently Coloured Substances, by which they operate on the rays of light, in producing colours.

No essential information, relative to this subject, can be obtained from any optical writers, who preceded Sir Isaac Newton. For, the origin and nature of light and colours were entirely unknown, till they were unfolded by his researches.

To him we owe the discovery of the different refrangibility of the rays of light; the invariable colours of the differently refrangible rays; the power of thin transparent plates, particles, and fibres, to exhibit several colours, according to their several thickneses and densities; as well as the investigation and explanation of several other properties of light.

All these were results of experiments made by means of Transparent Colourless Media. But, he does not appear to have examined, with equal attention and success, the properties of Permanently Coloured Bodies, and their operations on the

the rays of light. And indeed, from the state and extent of his researches, it was not possible that he could have attained to a clear insight into that part of Optics, as he was not furnished with any regular series of experiments, which could be applied to the solution of its phenomena.

As the progress of Sir Isaac Newton's discoveries did not extend beyond the limits of his experiments, it may be fairly concluded, that, without such sources of information, the most acute and penetrative understandings must fail of success in physical inquiries.

This great philosopher, however, in the few passages wherein he treats of Coloured Substances, constantly avows his defect of experiments. It is probable that, by this candid acknowledgment, he intended that the opinions which he had expressed, on this subject, which are merely conjectural or founded on abstract speculation, might be distinguished from those clear truths, which he had deduced from his numerous and accurate experiments, performed with Transparent Colourless Bodies.

Thus, having mentioned some of those substances, which transmit one sort of light and reflect another sort, he makes this remark: " If
" these liquors or glasses were so thick and massy,
" that no light could get through them, I ques-
" tion not but they would, like all other opaque
" bodies,

“bodies, appear of one and the same colour,
 “in all positions of the eye, though this I cannot
 “yet affirm by experience.”*

And he thus expresses himself, relative to the opacity of glass wedges filled with red, and blue liquors, when viewed conjointly. “This Mr. Hook tried casually with glass wedges filled with red and blue liquors, and was surprized at the unexpected event, the reason of it being then unknown; which makes me trust the more to his experiment, though I have not tried it myself.”†

We find, at the close of the Optics, a passage relative to the inflections of the rays of light and the colours made thereby, which seems capable of being extended to all those observations, which the illustrious author had left imperfect, or had not prosecuted with that eminent degree of industry and circumspection, which are generally conspicuous in his inquiries. It is as follows: “When I made the foregoing observations, I designed to repeat most of them with more care and exactness; but I was then interrupted, and cannot now think of taking these into farther consideration.”‡

Sir Isaac Newton was of opinion, that *all Coloured Matter reflects* the rays of light, some

* Newton. Opt. L. I. Part II. Prop. X. Probl. V.

† Ib.

‡ Ib. L. III. ad. calc.

bodies

bodies *reflecting* the more refrangible, others the less refrangible rays, more copiously. And that “this is not only a true reason of these colours, but even the only reason.”*

He conceived that opake bodies reflect the coloured light from their anterior surface, by some power of the body evenly diffused all over its surface, and external to it.

He thus delivers his doctrine relative to transparent coloured liquors.† “A transparent body “which looks of any colour by transmitted light, “may also look of the same colour by reflected “light, the light of that colour being reflected “by the farther surface of the body, or by the “air beyond it. And then the reflected colour “will be diminished, and perhaps cease, by “making the body very thick, and pitching it “on the back side to diminish the reflection of “its farther surface, so that the light reflected “from the tinging particles may predominate. “In such cases, the colour of the reflected light “will be apt to vary from that of the light “transmitted.”

As these opinions are merely hypothetical, and are not supported by the evidence of any experiments, I judged it expedient carefully to inquire into the phænomena of Coloured Substances,

* *Ib.* L. I. Part II. Prop. X. Probl. V.

† *Ib.*

from which alone any clear illustration of such questions can be attained.

For this purpose, I entered upon a series of experiments, which have been performed with Transparent Coloured Liquors, and Glasses, as well as with opaque, and semitransparent bodies.

I shall, in the first place, consider Transparent Coloured Substances; because they are of the simplest kind, as they consist only of the Colouring Particles united with, and diffused throughout, Transparent Media, such as spirit of wine, oil, water, or glass.

From the examination of such tinged media, I have been enabled to discover several properties of Coloured Matter, which are very different from those, which have hitherto been thought to prevail.

For instance, it will appear from the experiments which I shall relate in the sequel, that in Transparent Coloured Substances, the Colouring Matter *does not reflect any light*; and when by intercepting the light which was transmitted, it is hindered from passing through such substances, they do not vary from their former colour,* to any other colour, but become entirely *black*.

As

* Optical writers generally use the word *colour* in an equivocal sense: sometimes expressing thereby the primary colours, as opposed to whiteness: at other times including whiteness also. I have, throughout this inquiry, used this word

As the incapacity of the Colouring Particles of Transparent Bodies to reflect light, is deduced from experiments which are very numerous, and whose results are constant and invariable, it may be held as a general law, at least till some exception to it can be discovered.

This law will appear still more extensive, if it be considered that, for the most part, the tinging Particles of liquors, or other Transparent Substances, are extracted from Opaque Bodies; that the Opaque Bodies owe their colours to those particles in like manner as the Transparent Substances do, and that by the loss of them, they are deprived of their colours.

By experiments made with several Opaque Bodies, it will be shewn that they actually do not exhibit their colours, by reflecting the rays of light. And, by the same experiments, the means, by which they do produce their colours, will be hereafter explained.

For the purpose of observing the manner in which Transparent Coloured Liquors act upon the

word to express only the *primary colours*, or such a mixture of them, as does not compose whiteness, or any of the gradations between white and black; such as are called by Sir Isaac Newton, grey, dun, or russet-brown.

rays of light, I procured small vials of flint glass, whose form is a parallelepiped; the height of these, exclusive of the neck, is about two inches, and the base about one inch square; their necks are cylindrical, and are about two inches in length.

I covered the bottom, and three of the sides of each of these vials, with a black varnish; the cylindrical neck, A, and the anterior side, B, except at its edges, were left uncovered.

I carefully avoided leaving any crevices in the varnish, that no light might be admitted, except through the neck, or the anterior side, of the vials.

In these experiments, both the inner and exterior surfaces of the glass must be perfectly clean; and those liquors, which are apt to deposit a sediment on the bottom or sides of the vessels which contain them, must be put into the vials, only when the examination of them is intended: those, which



which are not subject to this inconvenience, may be constantly kept in the vials.

The uncovered side of the vial should not be placed opposite to the window, through which the light is admitted; because in that situation the light would be reflected from the farther side of the vial, and would be transmitted through the coloured liquor; and it is observable that smooth black surfaces reflect light very powerfully. Now as it is a principal object in the experiment that no light be transmitted through the liquors, this will be accomplished by placing the uncovered side of the vial in such a direction, that it may form a right angle with the window.

I have examined a great variety of Transparent Coloured Liquors, in vials, prepared and disposed as I have here described, and have constantly found that in every instance, that part of the liquor, which was contained in the neck of the vials, exhibited its colour distinctly and vividly; but, that portion, which was in the body of the vials, and which was viewed through the uncovered side, *exhibited no colour, but was black.*

From amongst numerous similar observations, I have selected those which are set down in the following table: I have not attempted therein to produce any regular or systematical collection of coloured liquors, but only to exhibit such specimens as may serve to shew the action of

B 3

vegetable,

vegetable, mineral, and animal colouring particles, on the rays of light.

The expressions, *reflected light*, and *transmitted light*, have been generally used, when Transparent Coloured Bodies have been considered. But, as the following experiments and observations, shew that Transparent Coloured Bodies are not endued with any *reflective* power, the word *reflected*, cannot properly be applied to the light which falls on them. I have, therefore, at the head of the last column of this table, substituted the words "*incident light*," instead of the usual expression, *reflected light*.

TABLE of TRANSPARENT COLOURED LIQUORS *viewed by*
TRANSMITTED, *and by* INCIDENT LIGHT.

LIQUORS.	By Transmitted Light.	By Incident Light.
1. Iron dissolved in the Nitrous Acid	Yellow	Black
2. Martial Alcaline Tincture of Stahl	Orange	Black
3. Vitriol of Iron dissolved in Water	Green	Black
4. Dilute Solution of Green Vitriol, with Infusion of Galls - - -	Blue	Black
5. Dilute Solution of Green Vitriol in Spirit of Wine, with Tincture of Galls in Spirit of Wine - -	Blue	Black
6. Saturated Solution of Fixed Alkali, in which a small quantity of Green Vi- triol is dissolved, with Infusion of Galls - - - - -	Red	Black
	7. Dilute	

L I Q U O R S.

	By Transmitted Light.	By Incident Light.
7. Dilute Solution of Green Vitriol, with Phlogificated Alcaline Lixivium	Blue	Black
8. Spa, and Pyrmont, Waters, with Infu- sion of Galls - - - -	Purple	Black
9. Solution of Vitriol of Copper -	Blue	Black
10. Copper dissolved in Nitrous Acid	Blue	Black
11. Cryftals of Verdegris, dissolved in Distilled Vinegar - - -	Blue <i>Green*</i>	Black
12. Copper dissolved in Volatile Alkali	Blue	Black
13. Manganefe fused with Nitre, or with Fixed Alkali, dissolved in cold Water	Green	Black
14. Manganefe, thus prepared, dissolved in hot Water - - - -	Purple	Black
15. Cobalt dissolved in Nitrous Acid	Red	Black
16. Marine Acid, to which a small quan- tity of Nitrous Solution of Cobalt is added - - - -	Green	Black
17. Sympathetic Ink of Cobalt -	Red	Black
18. Solution of Gold - - - -	Yellow	Black
19. Dilute Solution of Gold, with Solu- tion of Tin - - - -	Red	Black
20. Solution of Platina - - - -	Orange	Black

* The names of the colours, which are printed in *Italic characters*, express those to which the principal colours, contained in the table, incline.

LIQUORS.

	By Transmitted Light.	By Incident Light.
21. Red Flowers, infused in Spirit of Wine, slightly acidulated with Nitrous Acid - - - -	Red	Black
22. Red Flowers infused in Water, slightly acidulated with Nitrous Acid	Red	Black
23. Purple, and Blue Flowers, infused in Water, slightly acidulated with Nitrous Acid - - - -	Red	Black
24. Purple, and Blue Flowers, infused in Spirit of Wine, slightly acidulated with Nitrous Acid - - - -	Red	Black
25. The same Red Infusions, with the addition of small quantities of Solution of Fixed Alkali - - - -	Purple Blue Green	Black
26. Yellow Flowers infused in Distilled Water - - - - -	Yellow	Black
27. Yellow Flowers infused in Spirit of Wine - - - - -	Yellow	Black
28. Green Colouring Matter of Grass, and other Green Leaves, dissolved in Spirit of Wine - - - -	Green Yellow Red	Black
29. Prepared Turnfol infused in Water	Purple	Black
30. Juice of Black Currants - - -	Red	Black
31. Black Cherries, Black Currants, and other Black Fruits and Berries, infused in Spirit of Wine - -	Red	Black
32. Raspberries, and other Red Berries, infused in Spirit of Wine -	Red	Black

33. Spanish

L I Q U O R S.

	By Transmitted Light.	By Incident Light.
33. Spanish Annotto dissolved in Spirit of Wine - - - - -	Yellow	Black
34. Spanish Annotto dissolved in Caustic Vegetable Fixed Alkali - -	Yellow	Black
35. French Berries infused in Spirit of Wine - - - - -	Yellow	Black
36. French Berries infused in Distilled Water - - - - -	Yellow	Black
37. Sap Green infused in Spirit of Wine	Green	Black
38. Sap Green infused in Distilled Water	Green Yellow Red	Black
39. Indigo dissolved in Oil of Vitriol, and afterward diluted with water	Blue	Black
40. Indigo dissolved in Caustic Vegetable Fixed Alkali - - - - -	Green	Black
41. Litmas infused in Distilled Water	Red Purple Blue	Black
42. Prepared Archil, Water - - -	Purple	Black
43. Prepared Archil, Spirit of Wine	Purple	Black
44. Gamboge dissolved in Spirit of Wine	Yellow	Black
45. Dragon's Blood dissolved in Spirit of Wine - - - - -	Orange	Black
46. Weld infused in Distilled Water	Yellow	Black
47. Madder infused in Spirit of Wine	Orange	Black
48. Alkanet infused in Spirit of Wine	Red	Black
49. Alkanet infused in Oil of Turpentine	Red	Black
	50. Alkanet	

L I Q U O R S.

	By Transmitted Light.	By Incident Light.
50. Alkanet infused in Expressed Oils	Red	Black
51. Fustic infused in Distilled Water	Yellow	Black
52. Fustic infused in Spirit of Wine	Yellow	Black
53. Turmeric infused in Spirit of Wine	Yellow	Black
54. Turmeric infused in Distilled Water	Yellow	Black
55. Logwood infused in Distilled Water	Yellow	Black
56. Logwood infused in Thames Water	Red	Black
57. Logwood infused in Spirit of Wine	Yellow	Black
58. Red Saunders infused in Spirit of Wine	Red <i>Orange</i>	Black
59. Cochineal infused in Distilled Water	Red	Black
60. Cochineal infused in Spirit of Wine	Red	Black
61. Kermes infused in Distilled Water	Yellow	Black
62. Kermes infused in Spirit of Wine	Yellow	Black
63. Ox Gall, diluted with Distilled Water	Yellow	Black
64. Blood with Spirit of Sal Ammoniac	Red	Black
65. Spirit of Nitre impregnated with Phlogiston - - - -	Yellow	Black
66. The same with Distilled Water	Green	Black
67. Nitrous Spirit distilled from equal parts of Arsenic and Nitre -	Green	Black
68. The same with Distilled Water	Blue	Black

These

These experiments shew, that Transparent Coloured Liquors do not yield any colour by reflection, but by transmission only.

If these liquors are spread thin on any white ground, they appear of the same colours, which they had exhibited, when viewed in the necks of the vials; as the light reflected from the white ground is, in this case, transmitted through the coloured medium.

But when they are spread upon a black ground, they afford no colour. The black ground, however, should not be a polished body; as the light, reflected thereby, would be transmitted through the thin medium on its surface, and be tinged by passing through it.

I shall now proceed to relate some experiments, which were performed with tinged glasses: these being, in many respects, analogous to coloured liquors.

I made several parcels of colourless glass. That, which I principally employed in these experiments, consisted of equal parts of borax and white sand. The glass was reduced to powder, and afterwards ground, together with the ingredients by which the colours were imparted.

This method, of incorporating the tinging particles, is greatly preferable to mixing them with the raw materials. The glasses, thus composed, excel most others in hardness, and are scarcely inferior, in lustre, to real gems.

All

All the experiments, which have been made with *transparent coloured glasses*, shew that they appear vividly coloured, when they are of such a thinness, and are tinged so dilutely, that light is transmitted through them. But when they are in larger masses, and the tinging matter is more densely diffused through them, they are *black*. For, these as well as the *transparent coloured liquors* do not exhibit colours by reflection, but by *transmission* only.

I shall here instance some trials, which I made for the purpose of observing the proportions of tinging matter, which produce colour, or blackness.

I tinged glass green, by adding to it one sixtieth part of its weight of copper. It is indifferent whether the copper, used in this process, be calcined, or applied in its metallic state.

I made a blue glass, by the addition of zaffre, a purple glass by manganese, a red glass by gold, and yellow glasses by silver, and by calcined iron. I also made a yellow glass, similar to a topaz, by the admixture of a small quantity of pulverized charcoal: and the same colour was imparted by wheat flower, by rosin, and by several other inflammable matters.

From the masses of transparent coloured glass, which were thus composed, small pieces were separated, and ground by a lapidary, which resembled gems of their respective colours.

Having

Having formed pieces of such glasses, about two inches thick, I inclosed all their sides with black cloth, except at their farther, and anterior surfaces. Each of these pieces of glass vividly exhibited its colour, when viewed by transmitted light: but when the transmitted light was intercepted, by covering the farther surface, the anterior surface afforded no colour, but appeared *black*.

When plates of Transparent Coloured Glass, somewhat thicker than window glass, are viewed by transmitted light, it is well known, that they exhibit their several colours.

I intercepted the light, which was transmitted through such coloured plates, by fixing a piece of black cloth, contiguous to their farther surface. The plates, thus prepared, when placed in such a direction, that they form a right angle with the window, appear perfectly *black*.

From the phenomena, presented by such plates, two observations may be deduced. (1.) That the Colouring Particles do not reflect any light. (2.) That a medium, such as Sir Isaac Newton has described, is diffused over both the anterior, and farther surfaces of the plates, whereby objects are reflected equally, and regularly, as by a mirror.*

* Whenever it is said that light is reflected by the surface of any substance, it should be understood, from this expression, that the reflection is effected by the medium, diffused over its surface.

When

When a lighted candle is placed near one of these coloured plates, the flame is reflected by the medium, which is diffused over the anterior surface of the plate. The image, thus reflected, resembles the flame, in size, and colour. For, it is scarce sensibly diminished, and *it is not in the least tinged by the coloured glass.*

If the plate be not so intensely coloured, or so massy, as to hinder the transmission of the light of the candle, there appears a secondary image of the flame, which is reflected by the medium, contiguous to the farther surface of the glass. And as the light, thus reflected, passes back through the coloured glass, it is vividly tinged by it.

When the glass, used in this experiment is green, the secondary image of the flame assumes a bright green colour. When glasses of other colours are used, the colour of the secondary image is always the same, as that of the glass.

The secondary image is less, than that which is reflected from the anterior surface. This diminution is occasioned by the loss of that part of the light, which is absorbed, in passing through the coloured glass. For, whenever any medium transmits one sort of rays, more copiously than the rest, it stops a great part of the oppositely coloured rays. And much more light is lost, in its passage through coloured, than through pellucid colourless, substances.

In

In making these observations, it is proper to choose coloured plates of glass, which are not in every part of an equal thickness, that the secondary image may not be reflected in such a direction, as to coincide with, and be intercepted by, that which is reflected from the anterior surface.

When the plates are so thick, and so copiously coloured, that the light cannot penetrate to their farther surface, they appear intensely *black*, in whatever direction they are viewed, and they do not afford any secondary image; but only reflect from their anterior surface, the flame, or any other objects which are opposed to them. These objects are represented in their own proper colours, and are as free from any tinge, or adventitious colour, as those which are reflected from looking glasses, or specula made of white metals.

It is manifest from hence, that the colouring particles have no share in effecting this reflection. For, if they possessed any reflective power, whence is it that glasses, copiously stored with colouring matter, impart no colours to the images, which they reflect?

It appears, from these observations, that transparent coloured bodies, as well in a solid, as in a fluid, state, exhibit colours by transmission only, but do not reflect any colour.

The order of this inquiry leads me, in the next place, to the consideration of the Colouring Particles, *pure, and unmixed with other media.*

For

For the purpose of procuring masses made up of such particles, I reduced several Transparent Coloured Liquors to a solid consistence, by evaporation. When a gentle heat is employed in this operation, the Colouring Matter, which is thus concentrated, remains unimpaired, and capable of again imparting its colour unaltered, to other liquors.

In this state, the Colouring Particles *reflect no colour*, and, as no light is transmitted through them, they are *black*.

Amongst the liquors, which I evaporated, were the tinctures, and infusions, of the colouring particles of red, purple, blue, and yellow flowers, of logwood, brazil, fustic, turmeric, red saunders, alkanet, sap green, kermes, and all the other Transparent Coloured Liquors, enumerated in the preceding table, which are capable of being reduced to a solid consistence, without undergoing such changes, during their evaporation, as render them opaque.

The opacity, which some liquors are apt to acquire from the loss of part of their solvents, arises from various causes, such as the crystallization of saline matters, or the coalescence of the colouring particles, into masses which differ considerably, in density, from the menstrua in which they were dissolved.

The consideration of this subject is of much importance to the art of dying. I have constantly

stantly observed, that whenever colouring particles become opaque, their size renders them incapable of entering the pores of wool, silk, cotton, or linen, or of cohering to their surface. For, the attractive force, by which particles tend mutually to each other, and cohere, is weakened, in proportion as their bulk increases, so that the degree of magnitude of the colouring particles, which is essential to the opacity of liquors, is inconsistent with the minuteness, requisite to those means of union, by which dying is effected.

I shall select one instance, from amongst many which are applicable to these observations. I infused, in a pint of distilled water, such a quantity of fustic, that the water was saturated with its colouring particles. The aqueous part of this infusion was evaporated by a gentle, but continued, heat, till it was reduced to a solid mass.

The liquor, during every part of this process, continued transparent, and the solid extract, which it yielded, transmitted a yellow colour, when spread thin, but appeared *black*, when thicker masses were viewed.

Having prepared another pint of the same infusion, I evaporated half of the water, and left the remainder, till it was cold. In this state it became turbid, and opaque. When this liquor was filtered, a transparent infusion passed through the filter, and an opaque fecula was retained by

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the

the filter, which was afterward dried, and appeared to be a white powder, slightly tinged with yellow. This powder did not cohere to the filtering paper, but was easily separable from it. It was again soluble in water, and formed with it a liquor, in all respects, similar to the original infusion.

From these circumstances, it appears that a given proportion of water, or a sufficient degree of heat, is requisite to the solution of the colouring particles of fustic. And experience evinces that those particles, which are too gross to pass through filtering paper, are incapable of entering the pores, or firmly cohering to the surface, of bodies.

Many dying ingredients, such as the colouring particles of logwood, kermes, and various other matters, are soluble in water, in all proportions, and therefore their infusions are not subject to become turbid, or opaque, during their evaporation. And the solid extracts, obtained from these liquors, reflect no colour, but are *black*.

I also formed solid masses, by mixing with a small quantity of drying oil, pigments, which consist chiefly of colouring matter, unmixed with opaque ingredients, such as indigo, Prussian blue, and sap green. These paints exhibit their respective colours, when thin plates of them are viewed by transmitted light; but appear entirely
black,

black, when the transmitted light is intercepted, or when the masses are of a sufficient thickness.

Several fruits and berries, as black cherries, black currants, blackberries, and many others, afford instances of blackness arising from the dense state of the colouring matter. Their juices are red, when spread thin on a white ground, or otherwise viewed by transmitted light.

Thus it appears, from all the preceding experiments and observations, that Transparent Coloured Matter, whether diffused through colourless pellucid media, or condensed into solid masses, separate and unmixed, is not endued with any reflective power.

I shall proceed to consider the action, and properties, of the colouring particles of *opaque* coloured bodies, and the means by which their colours are produced.

The transparent liquors and glasses, which have been already examined, owe their colours to such particles extracted from opaque substances: and it has been shewn that those particles do not act upon light by reflection.

It has also been observed, that when coloured particles are spread thin upon any white ground, they exhibit their several colours, by transmitting the light reflected from the white ground.

I shall endeavour to prove, by several experiments and observations, that the colours of opaque bodies are produced by a similar operation.

Amongst the natural bodies, which are the objects of this inquiry, vegetables claim our principal attention, from the great variety and brightness of their colours.

In order to examine the leaves, fruits, flowers, wood, and roots of plants, I found it necessary to separate their component parts, on which their colours depend.

The following experiments, made with this view, have enabled me to discover the cause of those colours, and the manner in which they are produced.

I digested, in rectified spirits of wine, grass and other *green* leaves of plants: by this means a transparent green tincture was obtained, which consisted of the colouring matter, dissolved by the spirit. I filled one of the vials, (No. 28.) with this liquor, and viewing that part of it which was in the neck of the vial, I observed that it *transmitted* a vivid green colour; but the other part of the tincture, which was contiguous to the uncovered side of the vial, reflected no light, and consequently appeared *black*.

I poured, into a white china cup, a small quantity of this tincture, which, by its presence, imparted to the bottom of the cup a green colour, exactly resembling that of the leaves from which the matter had been extracted.

After the Colouring Matter had been taken from the leaves, the leaves remained apparently
unaltered

unaltered in texture, and in every other respect, except in their loss of colour.

In this state, they consist principally of the fibrous and vascular parts, and are either perfectly *white*, or have their *whiteness* slightly tinged with brown.

I digested also in rectified spirit of wine, red, purple and blue flowers. All these yielded, to the spirit, their colouring matter, and by the deprivation of it appeared *white*. From most of these flowers, the spirituous menstruum acquired either no colour, or only a faint tinge. But, when it was acidulated, it became red, and, by the addition of an alkali, assumed purple, blue, and green, colours. In each of these states, the coloured tinctures were examined in the vials, as in (No. 21, 24, 25.) and, also were poured upon a white ground. All of them, by these means, were found to yield bright colours by transmission, but none of them reflected any light.

I also digested red, purple and blue flowers, in water slightly acidulated with nitrous acid, and thus obtained from them red infusions, which I have been able to preserve many years, without the least alteration in their colour, by saturating them with sea-salt. (No. 22, 23.)

By the addition of very small portions of alkali, these red liquors also were changed to purple, blue, and green. All these coloured infusions

were viewed, in the same manner as the preceding liquors, and were found to yield vivid colours by *transmission*, but to *reflect no colours*. No. 25.)

The addition of the alcali must be very gradual: for if too much is added, at once, to the red liquor, the intermediate colours, between the red and the green, will be wanting. To half an ounce of the red infusion, it is proper to add, at once, only the least quantity of a solution of pearl ash, that can be taken up, upon the point of a pen, repeating this addition, slowly till each of the colours are produced.

The flowers, after having been repeatedly macerated in acidulated water, lost their colouring matter, and became *white*.

Yellow flowers also communicated their colours to water, and to spirit of wine. The infusions and tinctures of these flowers were subjected to the same experiments, as had been employed in the examination of the liquors already mentioned, and appeared yellow by *transmitted* light, but *did not reflect any colour*. (No. 26, 27.)

White paper, and linen, may be tinged, by dipping them in the infusions of the flowers of each colour: and by spreading, upon those *white* grounds, the expressed juices of such flowers, their colours may be communicated to the paper, and the linen.

These

These means of tinging are somewhat similar to the application of vegetable dyes to linen, and of transparent water colours to paper, many of which consist of the Colouring Matter of plants, such as indigo, litmus, sap green, gamboge, the vegetable lakes, and various others.

These operations are so well known, and the methods of executing them are so obvious, that I should not here have noticed them, if they had not led me to some observations respecting the *white* grounds, on which the colours are applied.

The consideration of those *white* substances affords much insight, into the manner in which the natural colours of vegetables are produced.

I have already shewn that, when the Colouring Matter of plants is extracted from them, the solid fibrous parts, thus divested of their covering, display that *whiteness*, which is their distinguishing character.

White paper, and linen, are formed of such fibrous vegetable matter; which is bleached, by dissolving and detaching the heterogeneous coloured particles.

When these are dyed, or painted, with vegetable colours, it is evident that they do not differ, in their manner of acting on the rays of light, from natural vegetable bodies: both yielding their colours by *transmitting*, through the

Transparent Coloured Matter, the light which is reflected from the white ground.

For it appears, from the preceding experiments, that *no reflective power* resides in any of their component parts, except in their *white matter* only.

This white matter frequently exists, without any considerable mixture, in plants, while they are in a state of vegetation: as in cotton, white flowers, the pith, wood, seeds, roots, and other parts, of several kinds of vegetables.

When decayed trees, and other plants, have been long exposed to the weather, after they have ceased to derive nourishment from the earth; their coloured juices are apt to be exhausted by the action of the rain, air, and sun; by which means the remaining substance becomes perfectly bleached.

The *white matter* of all vegetables is composed principally of an earth. Their ashes consist of this earth, separated from the inflammable, and evaporable parts, to which they owed their colours.

I have rendered ashes intensely white, by carefully calcining them; and afterwards grinding them with a small proportion of nitre, and exposing this mixture to such a degree of heat, as caused the nitre to deflagrate with the small particles of coal which remained unburnt; and lastly, by dissolving, in marine acid, the
ferruginous

ferruginous matter diffused through them, and repeatedly washing the remaining ashes in a sufficient quantity of water.

By mixing ashes, thus purified, with glass, together with an additional portion of borax, I obtained an opaque enamel remarkable for its whiteness.

From all these premises it appears, that the earth, which forms the solid substance of plants is *white*; that it is separable from the colouring matter by several means; that, whenever it is either pure and unmixed, or diffused through transparent colourless media, it exhibits its *whiteness*; and is the only vegetable matter which is endued with a reflective power.

I have hitherto described several cases, in which the *white matter of plants* may be brought to view, by the removal of the coloured particles which covered it. Its exposure may also be effected by other means.

It is well known that the vapour of burning sulphur whitens red roses. This effect is generally attributed to the vitriolic acid arising from the sulphur. But such an explanation is certainly erroneous, because the vitriolic acid, applied to the roses thus whitened, restores their red colour.

As sulphur is composed only of phlogiston and vitriolic acid, and as the whiteness is not caused by the acid, it is evident that it is effected by the phlogiston.

I exposed

I exposed several sorts of red, and purple flowers to the phlogiston, disengaged from hepar sulphuris decomposed by an acid, and to other phlogistic vapours, all of which whitened the flowers. I restored the red colour of each of these, by applying to them indiscriminately either vegetable, or mineral, acids.

It appears, from these experiments, that the colouring matter of the flowers is not discharged or removed, but only dissolved, by the phlogiston; and thereby divided into particles too minute to exhibit any colour. In this state, together with the vegetable juice in which they are diffused, they form a colourless transparent covering, through which the *white matter* of the flowers is seen untinged.

The Colouring Particles of plants consist principally of inflammable matter; and their solubility in phlogiston, and union with it, are analogous to the mutual action, which other inflammable bodies exert on each other. Thus, æther dissolves all essential, and expressed oils, animal empyreumatic oils, and resins. Sulphur, camphire, and almost all substances abounding in phlogiston, are soluble in oils, ardent spirits, or other inflammable menstrua.

The manner, in which the red colour of the flowers is restored, appears to me to be explicable from known chemical laws. When acids are applied to the whitened flowers, by their strong
affinity

affinity with the phlogiston which the sulphur had communicated, they unite with that principle, and disengage it from the colouring particles; which, being thus extricated, resume their original magnitude, and colour.

Fixed alkali, whose affinity also with phlogiston is very great, changes the whitened flowers to purple, blue, and green, which colours alkali always produces in such flowers.

The matter of light acts upon coloured bodies, in the same manner as the phlogistic vapours, whose operations have been here explained. Thus, dyed silk, or other stuffs, exposed to the sun's light, are deprived of their colour, in every part, which lies in the direction of the rays, whilst those parts preserve their colour, which are defended from the access of the rays by their folds, or by the intervention of any opaque body which intercepts the light.

The colours, thus impaired by the action of phlogiston or of light, may be restored by the means already described, if they are applied whilst the solution of the colouring particles is recent: but, afterward they are apt to fly off, and be entirely dissipated, on account of the volatility, which the inflammable principle constantly imparts to matter, with which it is united.

The action and properties of phlogiston, and of the sun's light, are so exactly similar, that the identity

identity of those subtile principles can scarcely be doubted.

White metallic calces, such as the magistery of bismuth, and the crystals and solutions of silver, mercury, and lead, are turned black by the inflammable principle, which they acquire from the sun's light, as well as from phlogistic vapours. And calcined ferruginous earths, which do not obey the magnet, become subject to its attraction, after they have been impregnated with phlogiston, by light collected in the focus of a burning glass.

It is certain that vegetables receive, from the rays of light, all that store of inflammable matter with which they are so richly supplied.

This principle cannot be furnished by the earth, as the small quantity of it, which the soil contains, is inadequate to the effect: and even this small portion is produced from the decomposition of vegetables, or animals which have derived their nourishment from vegetables. Plants, which, during their growth, are excluded from the solar light, abound in aqueous juices, but are deficient in oils, and other phlogistic products: and the privation of their other qualities, such as odour, taste, and colour, shews that the matter of light is essential to the vigour and perfection of vegetable substances.

Sir Isaac Newton was of opinion that "Gross
"bodies and light are convertible into one ano-
"ther, and that bodies receive much of their
"activity

“activity from the particles of light which enter
“their composition.”

He observes that “Bodies and light act mutually
“upon one another, that is to say, bodies upon
“light in emitting, reflecting, refracting and in-
“flecting it, and light upon bodies by heating
“them, and putting their parts into a vibrating
“motion wherein heat consists.”* And that the
mutual action between light and inflammable
bodies is much stronger, than between light and
other bodies.

In classing several kinds of bodies, according
to their refractive powers, he instances “Selenite,
“rock crystal, island crystal, vulgar glass, and
“glass of antimony, which are terrestrial stony
“concretes.”† To these substances which consist
principally of earth, and have the weakest refrac-
tive powers, he thus opposes the following inflam-
mable substances; “The refraction of camphire,
“oil olive, linseed oil, spirit of turpentine and
“amber, which are fat,‡ sulphureous, unctuous
“bodies, *and a diamond, which probably is an*
“*unctuous substance coagulated*, have their refrac-
“tive powers in proportion to one another as

* Newton. Opt. Qu. ad Calc.

† Ib. L. II. Part. III. Prop. X.

‡ Sir Isaac Newton, according to the custom of his time,
uses the words sulphureous, unctuous, &c. to signify what
later chymical writers express by the terms phlogistic or
inflammable.

“their

“ their densities without any considerable variation.
“ But the refractive powers of these unctuous substances, are two or three times greater, in respect
“ of their densities, than the refractive powers of
“ the former substances in respect of theirs.”

The clear conceptions which Sir Isaac Newton had formed, respecting the refractive power of the inflammable principle, afford an instance of unparalleled penetration and discernment.

Diamonds, from their apparent resemblance to crystalline vitrifiable stones, and gems, were universally held, by naturalists and lapidaries, not to have differed, in their constituent matter, from such stones and gems, except in a greater degree of purity.

Sir Isaac Newton, judging of diamonds by their refractive power, classes them with inflammable bodies, and as they are endued with the strongest refractive power, he does not scruple to rank them at the head of the inflammable bodies, as consisting of the purest phlogiston.

This remarkable observation has not, I believe, ever been noticed, by philosophers, or naturalists, as an object of their consideration: doubtless, because they were prejudiced by the apparent qualities of diamonds, and their resemblance to those of other gems, which seem to have withheld their attention from the powers and properties, the discovery of which was drawn from the more certain test of optical investigation.

After

After Sir Isaac Newton had published his Optical Works, almost a century had passed, during which no experiments were made, whereby the constituent matter of diamonds could be ascertained. Several eminent chymists, and philosophers, in France, have recently applied great skill and industry in the examination of that subject.

From their inquiries, it appears that diamonds, when enveloped in powdered charcoal, and inclosed in crucibles carefully luted, resist the force of fire, and remain unaltered, in the same manner as charcoal, and other solid inflammable bodies.

When exposed, under a receiver, to the focus of a large burning glass, they impart phlogiston to the air which is contained in the receiver.

When placed, under a muffle, upon a cupel or stand of white calcined refractory earth, in a degree of heat sufficient to melt pure silver, the diamonds send forth a continued flame, and thus entirely burn away.

When exposed to the fire, in thick vessels of white porcelain, perfectly closed with stopples of the same substance, so that their cavities contain only air and the inclosed diamonds, they are entirely dissipated, and disappear, without leaving the least trace of the matter, of which they were formed.

These experiments prove, that diamonds consist of phlogiston; and they are the only natural substance,

stance, in which that principle appears to exist pure and unmixed. For all inflammable liquors contain water: and all solid inflammable bodies leave a residuum of ashes, or coal, accordingly as they are burnt in open, or in close vessels.

Nor can any constituent parts of bodies pass through solid substances, except only phlogiston, and light. And from their agreement in this respect, the identity of these subtile principles is farther confirmed.

From the native form, and constituent matter of diamonds, may they not be properly defined *crystallized phlogiston*?

The chemical experiments, respecting the inflammable nature of diamonds, carry with them the greater clearness and conviction, as the philosophers, who made them, were entirely unprejudiced in their inquiries on that subject: for they do not seem to have been aware that Sir Isaac Newton had discovered, from optical observation, the same truth to which they were led by the chymical phænomena.

The solvent power of phlogiston, whether obtained from terrestrial bodies, or proceeding immediately from the light of the sun, is manifest in various instances similar to those which have been hitherto explained.

Silk is whitened by the phlogistic vapours of sulphur: and this operation does not appear to differ

differ from the change effected in flowers by the same vapour.

The light of the sun is found to be a necessary, and essential, agent in bleaching linen, bees' wax, and various other substances. Some part of the colouring matter, which impairs the whiteness of such bodies, not yielding to the power of any other solvent.

Red flowers are whitened by the electric spark, of whose inflammable nature we cannot entertain the least doubt. For the spark itself is a bright flame, and it yields the same smell, which all other phlogistic matters impart.

The electric spark, in like manner changes the blue infusion of turnsol, to red. The effects which it produces on the turnsol, and on red flowers, do not differ from each other, except in degree only. For, when vegetable matter is dissolved, it is changed from blue, to red; and when it is farther dissolved, it is divided into particles too minute to exhibit any colour.

A due attention to the changes of colour, and other effects, arising from the solvent power of phlogiston, will afford much insight into several operations of the arts and manufactures, and will furnish an explanation of many appearances, which occur in chymistry, and physics, which cannot otherwise be rightly understood.

The perfection of the arts of dying, and bleaching, and of preparing and preserving painters'

D

colours,

colours, essentially depend on the knowledge of this subject.

Solutions effected by means of phlogiston, frequently are wrongly attributed to the operation of supposed acid menstrea: as several kinds of substances are capable of being dissolved indiscriminately, either by acids, or phlogiston.

For the purpose of distinguishing, in any instance, between the action of the acid solvents, and that of the inflammable menstrea, it is proper to examine the nature of the matter, by which either of those principles is furnished.

Fixed air is generally supposed to possess an acid quality, and several of its properties are ascribed to its acidity.

The change of colour, produced in vegetable juices by the electric spark, is adduced as a proof of the acidity of fixed air. But it has been already shewn that this effect does not arise from acid, but from phlogistic, matter.

The acid quality of fixed air is also generally inferred, from its power of dissolving iron. But, phlogiston also is a solvent of iron. Thus, a considerable portion of that metal is always dissolved and held in solution, by the phlogisticated alkaline lixivium, which consists of inflammable matter calcined with fixed alkali. M. Margraf has shewn that several other metals are soluble in this lixivium. Hence it is evident that the solubility of iron does not prove the acidity of the solvent, but may arise from the phlogiston contained in it.

Fixed

Fixed air, by its combination with alcalies, diminishes their causticity, and promotes their crystallization. These properties are also supposed to be communicated by an acid, imparted by fixed air.

But, this hypothesis does not agree with the effects, which are produced by the combination of acids with alcalies. For, neutral salts are formed by the addition of acids to alcalies. And as alcalies do not become neutral salts, by their union with fixed air, but are only changed thereby, from caustic and deliquescent, to mild alcalies, capable of crystallizing, it is evident that the alteration, which fixed air causes in them, does not result from the introduction of an acid.

We must, therefore, turn our views to the consideration of some other principle, by which these effects may be produced.

It appears from various chymical processes, that alcalies are rendered mild, and capable of crystallizing, in proportion as they are united to phlogiston. The phlogisticated alkaline lixivium, when saturated, is perfectly mild, and, by a slight evaporation, is reduced to a concrete crystalline mass which does not deliquesce, or imbibe the least moisture from the air, and no longer retains any alkaline character or property.

M. Beaumé, by an elegant and ingenious experiment, has proved the presence of phlogiston in mild alcalies, and has shewn that their power

of crystallizing depends upon their union with that principle.

He heated, in a silver vessel, a lixivium of mild alkali, which imparted to the silver a covering, or coating, of inflammable matter, by which its surface was tarnished, and became black. The lixivium was several times poured out of the silver vessel, and after the surface of the silver had been freed from the tarnish, the lixivium was replaced in it, and again heated, by which the tarnish was renewed. This was repeated till the lixivium no longer communicated any stain to the silver.

The causticity of the lixivium increased, in proportion as it imparted its phlogiston to the surface of the silver, and, at the end of the process, the alkali became perfectly caustic, and incapable of crystallizing.

These instances, and many others which might be adduced, seem to prove that the change, which fixed air produces in caustic alkalies, is not effected by acid, but by phlogistic matter.

It is certain that the matter, communicated to lime by fixed air, is the very same which it imparts to alkalies. For it may be transferred, unchanged, from one of those substances, to the other; and, when united to either of them, still retains the same *qualities*. Therefore, if phlogiston renders alkalies mild, and effects their crystallization, the same principle also precipitates lime, and,

and, in like manner, restores it to its state of mild calcareous earth.

The experiments and observations, on which Dr. Black has established his comprehensive and consistent theory, clearly prove, that lime is precipitated from lime water, by fixed air: but his views were not extended to an investigation of the particular matter, or quality, whereby fixed air operates that effect.

Lime which has been precipitated from lime water, and restored to the state of a mild calcareous earth, is again soluble by the addition of a larger proportion of fixed air. This solution is attributed to the acid quality of fixed air; and it has been considered as a strange and extraordinary circumstance, that accordingly as different proportions of it are applied, it should act as a precipitant, and a solvent, of the same substance.

The simplicity, which nature observes in all her operations, will not permit us to suppose, that fixed air is possessed of two different or opposite qualities, by one of which it precipitates, and by the other of which, it dissolves.

The precipitation of lime from lime water, and its resolution, are effected by an equable uniform action, exercised by one and the same simple principle, which is a constituent and essential part of fixed air. And, such a precipitation, and resolution, are not extraordinary or complex phenomena, as they have been esteemed, but are

analogous to the ordinary and constant effects, which arise from chymical affinities.

This may be exemplified, by any compound which assumes a concrete solid consistence, by its union with a given quantity of a fluid, and which, by the addition of a larger quantity of the same fluid, is reduced to a liquid state.

Thus, when a due proportion of water is added to iron, and vitriolic acid, a mutual attraction takes place between these three ingredients, by means of which they are united, and, by their combination, a concrete vitriol, or metallic salt, is formed. But, if a greater quantity of water be added to this concrete salt, as the mutual attraction, after this addition, subsists equably between the vitriolic salt and the whole mass of water, the acid and ferruginous particles are more minutely divided, and diffused uniformly throughout every part of the water. And thus, the solid concrete salt is resolved, and a vitriolic liquor is formed, in which the water predominates.

Lime strongly attracts and unites with inflammable substances, such as sulphur, camphire, and resins. Fixed air has a still greater affinity to lime. Because in all the grosser substances, the phlogiston is allayed by salt, earth, and other matters: but, in fixed air, it exists in a purer, and consequently, a more active state.

As alcalies are rendered mild, or caustic, by the presence, or absence, of the inflammable principle,

ciple, it can hardly be doubted that the difference between mild calcareous earth, and quicklime, is also occasioned by a communication, or deprivation, of the same principle.

The origin of fixed air, seems to prove its phlogistic nature. For all bodies, which yield it, afford also inflammable matter: but many of them do not yield any acid. Calcareous spar, magnesia, and alkaline salts, send forth fixed air, and all these substances, by the loss of it, are deprived of their inflammable contents: diamonds, exposed to the focus of a burning glass under a receiver, impart to the air, contained in it, a power of precipitating lime, from lime water, when it is agitated with it. But it does not appear that any acid can be derived from those bodies.

Some of the properties of fixed air are consistent with either the character of acid, or of phlogiston. Such are, its power of altering the colour of vegetable juices; its affinity to alcalies; and ready union with lime; its power of dissolving iron, which is instanced in all acids, and in the phlogisticated alkaline lixivium; the antiseptic quality prevails equally in acids, and in inflammable spirits; acids are disengaged from substances, which are decomposed by stronger acids, phlogiston is likewise expelled from bodies, which are dissolved in acids.

The qualities of acid, and phlogiston, agree in these, and in several other instances, but fixed air

is endued with properties, which are peculiar to phlogiston. Such as its power of effecting the crystallization of alcalies, without changing them to neutral salts; its tendency to escape from water, and its affinity with the air, by means of which a considerable quantity of fixed air is united with, and diffused throughout, every part of the atmosphere.

Water, as well as phlogiston, is a constituent part of all substances which yield fixed air. Both these principles have a strong affinity to air. This appears from the union which air forms with the inflammable principle, when it is disengaged from bodies by combustion, fermentation, putrefaction, or any other mode of decomposition; and from the mutual attraction of water and air, which is manifested by evaporation, and by the constant presence of aqueous particles in the atmosphere.

The laws of chymical analysis will hardly permit us to doubt, that the air, which is obtained from mild alcalies, calcareous earth, and various other substances, receives from them when they are decomposed, the same contents which were united in them as constituent parts, while they were in their intire state. And their analysis invariably shews that air, water, and phlogiston, enter their composition.

From hence it seems to follow, as an immediate and obvious inference, that fixed air consists of these three ingredients, either united in bodies,
and

and discharged from them, already combined, or that it is formed in the atmosphere, by the concurrence and union of these principles. And all the phænomena, not only of fixed air, but also of phlogisticated air, may be solved by the action, and properties, of these ingredients.

The weight of fixed air, indicates that it contains a considerable portion of aqueous matter; and it is by means of this constituent principle, that it is miscible with water, in like manner as ardent spirits are, notwithstanding their inflammable nature. The phlogistic part of fixed air has been already considered.

Phlogistic matters are miscible with water, only in proportion as they contain a quantity of the aqueous principle in their composition. When the relative proportion of this constituent part, is less than that of the phlogiston combined in such matters, they are either immiscible with water, or only miscible in part.

Thus, spirit of wine, which is oil combined with water, unites with water, in all proportions.

Æther, which consists of spirit of wine, from which a considerable portion of its water has been separated by the vitriolic acid, is not miscible with water in all proportions: but, ten parts of water are requisite to the absorption of one part of æther.

Oil, which contains still less water in its composition,

position, does not, in any degree, mix with water.

Resinous substances do not combine with water, because their aqueous part is not in sufficient quantity to serve, as a medium, for the union of their phlogiston.

In gums, the relative proportion of phlogiston is much less than in resins, and that of the water is much greater: and by the intervention of their aqueous part, gums are readily miscible with water.

Resins, when united with a due proportion of gum, are by its mediation, also rendered soluble in water. But, if a less proportion of the gum be joined with the resin, only a part of the compound, resulting from this union, is disposed to mix with water, and a residuum is left, which is incapable of being dissolved in any aqueous liquor.

Fixed air seems to resemble these matters, which do not possess a sufficient quantity of the aqueous medium, to render them totally soluble in water. For, after a given portion of fixed air has been imbibed by water, a residuum remains, which is incapable of being absorbed by it, and is called phlogisticated air.

This air may be formed from fixed air, not only by the subtraction of water, but by the addition of the inflammable principle: as when phlogiston is communicated to fixed air by electric sparks, or
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the vapours disengaged from a mixture of sulphur and iron filings.

The origin of phlogisticated air shews, that its difference, from fixed air, consists chiefly in its deficiency of water.

As metals contain no water, so the phlogiston, which arises from them during their calcination, does not produce fixed air, but phlogisticated air.

But vitriols, and all other saline matters, contain water as a constituent part, and therefore yield fixed air. Calces of metals also, which have received aqueous matter, in the process of their calcination, as white lead, and other calces which have absorbed water, together with air, from the atmosphere, also yield fixed air.

The fermentation, and putrefaction, of vegetable and animal substances, is effected by means of their moisture, and therefore, by these modes of decomposition, fixed air is produced.

Fixed air is more effectually formed by respiration, than by many other phlogistic processes, in consequence of the copious supply of the aqueous, as well as the phlogistic, principle, which the air receives from the lungs.

Fixed air may be formed from vegetable acids, but when it is thus constituted, it does not differ from that which is produced from alcalies, magnesia, calcareous spar, and various other substances, which yield no acid. It is therefore evident, that in each of these instances, it is formed by the combination

combination of some principles, which are common to all those substances.

These principles are water, and phlogiston. In vegetable acids, the phlogiston combined with the water, is equal, in quantity, to that which constitutes the inflammable part of spirit of wine: for radical, or concentrated, vinegar, is totally inflammable.

The acid state of vegetable matters is not essential to them, nor is it requisite to their production of fixed air. For, fixed air is producible from plants, when they are recent; when they are in a vinous state, and afford ardent spirits; and also when they are in a state of putrefactive fermentation. From whence it appears that in their acid, as well as in their recent, vinous, or putrefactive state, they yield fixed air, by means of their aqueous, and phlogistic, principles.

All fixed air, from whatever subject it is procured, or to whatever bodies it is transferred, consists, constantly and invariably, of the same materials, combined in the same proportions: otherwise it could not restore lime, caustic alcalies, or other matters, to their original mild state: because, these substances cannot be recomposed, but by the same proportion of their constituent principles, which they contained, before their decomposition.

Thus, lime cannot be restored to the state of mild calcareous earth, by water, or by pure dephlogisticated

phlogisticated air, because each of these principles consists of only one of the three ingredients, which are requisite for that purpose.

Nor can the recomposition of calcareous earth be effected by phlogisticated air, because it contains an excess of phlogiston, and a defect of water.

Compounds, formed of such relative quantities of any of these principles, as do not constitute fixed air, may acquire a due proportion of them, by an addition of the ingredients in which they are deficient.

Pure dephlogisticated air is reduced to fixed air, by the communication of aqueous, and phlogistic vapours, disengaged from bodies, by various modes of decomposition: these principles readily combine with air, on account of their great affinity to it.

Phlogisticated air, when agitated with water, receives into its composition a quantity of aqueous particles, sufficient to constitute it fixed air: and by that means, it becomes capable of precipitating lime, from lime water.

If the analysis, and recomposition, of calcareous earth be ever so often repeated, its analysis will always yield, and its recomposition will always require, the same relative quantities of air, water, and phlogiston.

Fixed air therefore, seems to consist of these three principles invariably, and constantly, combined in the same proportions.

I shall

I shall not here enter upon the consideration of any other aëriform fluids, because they are foreign to my present inquiry.

I was led to an examination of the inflammable principle, by the changes, which it operates in coloured substances, both when it is in a detached and separate state, and when it forms a constituent part of fixed air, and is diffused throughout the atmosphere.

Fixed air has been frequently considered as a mere compound of air, and phlogiston. But, such a compound seems to approach nearer, in its nature, to phlogisticated air; as it is deficient in one of the principles, which is essential to fixed air.

I have endeavoured to point out some qualities of the inflammable principle, which have not hitherto been observed, or which have not been applied to the solution of the phænomena of elastic fluids. Such are, its solvent power; its power of effecting the mildness, and crystallization of alcalies; its strong affinity to calcareous earth, alcalies, and other substances which yield fixed air, whose similar, and correspondent, properties result from the phlogiston, which it contains as a constituent part.

I willingly submit these observations, to the candid judgment of those excellent philosophers, who have extended the knowledge of elastic fluids, by their instructive labours: amongst which, the
numerous

numerous experiments and observations of Dr. Priestley are the most conspicuous.

From the preceding experiments and observations it appears, that the colouring particles of flowers and leaves, are soluble in acid, and phlogistic, menstrua.

The other parts of vegetables consist of materials, similar to those which are contained in their flowers, and leaves, and undergo the same changes, from the same causes. I extracted from logwood, its colouring particles, by repeatedly boiling it in water. The wood, thus deprived of its tinging matter, no longer retained its yellow colour,* but was of a brown hue, similar to oak wood.

I macerated some pieces of logwood thus deprived of its colour, in aqua fortis, and, after they had undergone the action of that acid, they were washed in a sufficient quantity of water. The wood by these means was reduced to *whiteness*.

* Most authors who treat of colouring substances, describe logwood, as a *red* wood. I have never procured logwood which was of any other colour, than *yellow*. It imparts yellow and orange colours to distilled water. Other waters extract a red tinge from it, by means of the alkali which they contain. These observations are also applicable to the other dying woods, to kermes, and various other articles of the *materia tinctoria*. I shall only add that the tinctures, infusions, and solutions, which are enumerated in the preceding table of coloured liquors have been described from careful and repeated observations.

By

By a similar treatment, fustic, and other dying woods, were deprived of their Colouring Matter, and became *white*.

I have hitherto shewn, that the Colouring Matter of plants does not exhibit any colour by reflection, but by transmission only; that their solid earthy substance is a white matter; and that it is the only part of vegetables, which is endued with a reflective power; that the colours of vegetables are produced by the light reflected from this white matter, and transmitted from thence through the coloured coat, or covering, which is formed on its surface by the colouring particles; that, whenever the colouring matter is either discharged, or divided, by solution, into particles too minute to exhibit any colour, the solid earthy substance is exposed to view, and displays that *whiteness*, which is its distinguishing character.

Animal substances do not afford any great variety of coloured products. But, in all those animal matters, which do exhibit colours, the colouring particles are endued with the same properties, and are regulated by the same laws, which prevail in vegetable substances.

The tinctures and infusions of cochineal (No. 59, 60.) and of kermes (No. 61, 62.) yield their colours, when light is transmitted through them, but do not reflect any colour.

The principal animal coloured substances are the bile, and the blood. I diluted, with distilled water,

water, fresh ox gall and examined it, in the vial (No. 63.) that part of it which was in the neck of the vial, and which was viewed by transmitted light, was yellow, the anterior surface reflected no colour, but appeared *black*.

Flesh consists of fibrous vessels containing blood, and is perfectly *white*, when divested of the blood, by ablution. The membranes, sinews, bones, and other solids, are *white*, and when they are freed from their aqueous and volatile parts, they are a mere white earth, unalterable by fire, and capable of imparting to glass an opaque whiteness.

Blood, diluted with warm water, was examined, in one of the vials. It transmitted a red colour; its anterior surface was almost, but not entirely, black. For it received a slight mixture of a brown hue, from some particles which were coagulated, and were suspended in the red liquor.

That I might procure blood, sufficiently diluted, and at the same time, perfectly and equably dissolved, I mixed as much red cruor, with spirit of sal ammoniac, as imparted to it a vivid red colour. The liquor, thus composed, was viewed in the vial, (No. 64). That part of it, which was contained in the neck of the vial, transmitted a bright red; that which was viewed through the anterior side of the vial, reflected no colour but was intensely *black*.

From these observations, it appears that the florid red colour of the flesh arises from the light

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which is *reflected* from the *white* fibrous substance, and transmitted back through the red transparent covering, which the blood forms on every part of it.

The blood, whilst recently drawn, does not assume the appearance which is common to transparent coloured liquors, for, such liquors, when too massy to transmit light from their farther surfaces, are black. But blood, recently drawn, yields a red colour, in whatsoever masses it is disposed.

The colour, thus exhibited, arises from a white matter diffused throughout the blood. The white matter is easily separable from the red part of the cruor. This may be performed, by dividing the cruor, after it is coagulated, into thin pieces, upon which a sufficient quantity of water must be poured. The cruor communicates a red tinge to the water, which should be changed every day. After a few days, the water no longer receives any tinge, and the remaining masses of the cruor are, by these means, rendered perfectly *white*.

Thus it appears that not only the flesh, but also the blood itself, are white substances, tinged with red particles.

The red colour, which the shells of lobsters assume, after they are boiled, is a mere superficial covering, spread over the white calcareous earth of which the shells are formed, and may be easily removed by scraping, or filing the surface.

Before

Before this superficial covering is attenuated, by the heat, it is much denser, so that, in some parts of the shells, it appears black: as it is too dense to admit the passage of the light to the white substance of the shell, and back again. But where this transparent blue colour is spread thinner, and rarer, the light, reflected from the white substance of the shell, is transmitted back through the blue film, and yields a light blue colour.

The colour, of the shells of several species of eggs, is also merely superficial, and may be scraped off, leaving the white earth of the shell exposed to view.

Feathers, in like manner, owe their colours to thin layers of Coloured Matter, covering the white substance, of which they are principally formed. I scraped off the superficial colour from such parts of vividly coloured feathers, as were solid enough to admit of that operation, and, by this means separated the coloured layers, from the white ground, on which they had been naturally spread.

The surfaces of the lateral fibres of feathers cannot be thus separated, on account of their minuteness. But, as they appear, when viewed in a microscope, nearly to resemble, in their form, the feathers themselves, it seems probable that their colours arise from a similar matter, and conformation, in the smaller fibres, as in the grosser parts of the feathers.

The colours of all the animal substances, which have fallen under my observation, are effected in

the same manner as those of the specimens which I have here described.

In all these instances, the colours of the bodies are produced by the light reflected from a white substance, and transmitted back from thence, through a transparent coloured covering. The colouring particles have been extracted from such of the bodies, as were capable of yielding them to any proper solvents: and in their state of solution, as well as when condensed into a solid consistence, they have been constantly found to possess a power of transmitting colour, but to be devoid of any reflective power.

In the examination of some animal subjects, when the colouring matter could not be separated from the white substance, by chymical means, I have had recourse to mechanical methods of effecting their division. But, such methods can only be employed, when the principal part of the white substance is unmixed with the coloured coat or covering, which is spread upon its surface.

The mineral kingdom affords a great variety of coloured substances. These consist principally of earthy, and metallic matters.

The earths have been usually arranged in three classes, the siliceous, the calcareous, and the argillaceous, which is obtained purest in the earth of alum. To these, mineralogists have lately added magnesia, and terra ponderosa, which is the basis of spar. All these earths are perfectly
white,

white, when pure, and free from heterogeneous matters.

The colours, which they assume, are adventitious, and arise from phlogistic, or metallic, mixtures. Such compounds form ochreous, cupreous, and other metallic earths, and coloured clays, and boles: which may be artificially obtained, by precipitating metals from their solutions, and uniting them with calcareous, or aluminous bases.

Calcareous earth indurated constitutes marble, which may be tinged, by means of metallic solutions, with dyes which, both in their colours, and materials, are similar to those produced by nature.

From siliceous earths, flints are formed, which owe their colour to phlogiston, and when sufficiently heated, are rendered white, by the loss of their inflammable contents.

Siliceous earths impregnated with metals, form agates, cornelians, jasper, and coloured crystals.

The emerald, sapphire, topaz, hyacinth, and ruby are composed of a mixture of siliceous, calcareous, and argillaceous earths, and receive their colours from iron.

All these coloured stones may be imitated by glasses tinged with such phlogistic, or metallic matters, as enter the composition of the original substances.

Liquors, impregnated with phlogiston (No. 65, &c.) transmit coloured light, but do not reflect any colours. Nor do the glasses which derive their colours from inflammable, or metallic matters, appear coloured by reflection, but by transmission only.

From hence it is evident, that phlogistic, or metallic matters, when united with earths, do not reflect the coloured light: but are transparent coloured media, which transmit the light reflected by the particles of the white earths.

Metals, when in their entire metallic state are endued with a strong reflective power. All the metals, except gold and copper, act equally upon all the rays of light, from which their whiteness arises.

Gold exhibits a white light, which is *tinged with yellow*. I have used this expression, because it appears, from experiment, that gold reflects a white light, and that its yellow colour is a tinge, which is superadded to its whiteness. The experiment is thus set forth by Sir Isaac Newton.*
“ Gold in this light, (that is, a beam of white
“ light) appears of the same yellow colour as in
“ day light, but by intercepting at the lens a
“ due quantity of the yellow making rays, it
“ will appear white like silver, as I have tried,
“ which shews that its yellowness arises from the

* Newton. Opt. L. I. Part II. Prop. XI. Prob. VI.

“ excess

“ excess of the intercepted rays tinging that
“ whiteness with their colour, when they are let
“ pass.”

I have already shewn, by numerous experiments, in what manner coloured tinges are produced ; and it uniformly appears, from all those experiments, that colours do not arise from reflection, but from transmission only.

A solution of silver is pellucid and colourless. A solution of gold (No. 18.) transmits yellow, but reflects no colour. This metal also when united with glass, yields no colour by reflection, but by transmission only.

All these circumstances seem to indicate, that the yellow colour of gold arises from a yellow transparent matter, which is a constituent part of that metal, that it is equably mixed with the white particles of the gold, and transmits the light which is reflected by them. In like manner as when silver is gilt, or foils are made by covering white metals with Transparent Colours.

But, these factitious coverings are only superficial, whereas the yellow matter of gold is diffused throughout the whole substance of the metal, and appears to envelop and cover each of the white particles.

In whatsoever manner the yellow matter of gold is united to its white substance, it exists in a rare state. For it bears only the same

proportion to the white particles of the gold, as that part of the yellow-making rays, which were intercepted, bears to all the other rays comprized in the white light of the sun.

Calces are metals, divested of their phlogistic principle, by menstrua, or by fire. The calcined particles are suspended in their solvents, and, together with them, form transparent liquors. The metals, thus dissolved, reflect no colours, but either transmit coloured light, or are pellucid and colourless.

It is proper here to explain the cause, why the metallic particles, which yield no colour, by incident light, when suspended in their solvents, are disposed to exhibit colours, when separated from their menstrua, and reduced to a calciform state.

Sir Isaac Newton has shewn, that when spaces, or interstices, of bodies are replenished with media of a different density, the Bodies are Opake; that those superficies of transparent bodies reflect the greatest quantity of light, which intercede media that differ most in their refractive densities; that the reflections of very *thin Transparent Substances* are considerably stronger, than those made by the same substances of a greater thickness.

On these grounds, the minute portions of air, or of the rarer medium, which occupies spaces void of other matter, reflect a vivid *White Light*, whenever their surfaces are contiguous to media, whose densities differ considerably from their own. So
that

that, every small mass of air, or of the rarer medium, which fills the pores, or interstices, of dense bodies, is a minute white substance.

This is manifest, in the whiteness of froth, and of all pellucid Colourless Bodies, such as glass, crystal, or salts, reduced to powder, or otherwise flawed. For, in all these instances, a *White Light* is reflected from the air, or rarer medium, which intercede the particles of the denser substances, whose interstices they occupy.

All pellucid Colourless Substances become opaque and white, by the admixture of pellucid colourless media of considerably different densities: as in the instances which have been here adduced. And all Opaque White Substances are rendered pellucid and colourless, by reducing them to uniform masses, whose component parts are, every where, of nearly the same density. Because, all reflections are made at the surfaces of bodies differing, in density, from the ambient medium; and, in the confines of equally dense media, there is no reflection.

Thus, opaque white earths are reducible to Pellucid Colourless Glasses, by proper fluxes, and a sufficient degree of heat. When the particles of air and water, united in the small bubbles of which white froth consists, are separated from one another, each of them constitutes an uniform, Pellucid, Colourless Substance.

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When particles of air, or of the rarer matter, occupy the interstices of any dense *Transparent Coloured Body*, the *White Light* reflected from those rare substances shines through the *Transparent Coloured Medium* which the particles intercede, and is tinged by it, according to the colour which it transmits.

Thus, an infusion of cochineal transmits a red colour, and its surface is *black*, when viewed by incident light. But, if this liquor be agitated, its surface is thereby covered with a red froth, whose colour is occasioned by the light, reflected from the globules of air inclosed in each of the bubbles, and transmitted back through the transparent films of red liquor, which cover them.

I tinged several masses of glass with metals so intensely, that they appeared *black*, except in such parts as, from their thinness, transmitted the Coloured Light. Pieces of these glasses were pulverized separately, and each of the powders, thus prepared, exhibited the respective colours, with which the several masses of glass had been tinged.

The action of such powders, on the rays of light, arises from the discontinuity of their parts, whereby the air is admitted into their interstices, and, by its reflective power, produces those appearances, which result from rare media contained

tained in the pores of Transparent Coloured Substances.

It is evident that calces, separated from metallic solutions, derive their power of exhibiting Coloured Light from the same causes, which prevail in those instances which I have here adduced, and explained. For, in proportion as the interstices of the calces are evacuated, by the deprivation of their liquid solvents, the air pervades those vacuities.

Vitriols, and other metallic salts, are formed from metallic solutions, by the evaporation of their aqueous part, excepting only such a portion of it as is essential to their crystallization.

These metallic salts are either coloured, or colourless, according to the solutions from which they are formed. Whilst their constituent principles remain united in due proportion, and order, they are pellucid. But when their watery part is disengaged, they lose their transparency, and texture, and are reduced to an opaque friable mass, or to powder.

In this state, air pervades the interstices which the water had evacuated, and reflects a white light, in consequence of the difference of its density from that of the matter which is contiguous to it; and as even the coloured vitriols, and other coloured metallic salts, contain a large proportion of colourless saline matter; when the water of their crystallization is expelled, their
metallic

metallic coloured particles are so diluted, that the mass appears almost white.

These effects are also produced by pulverizing, or otherwise flaving, metallic salts, but not so compleatly as by the expulsion of their water.

By calcination, the saline matter is driven off: and, when this operation is effectually performed, the calces consist of metallic particles, which are free from all extraneous matter, excepting only the *moleculæ* of air which occupy their interstices.

The air, which intercedes the particles of metallic calces, reflects the light more strongly than that which intercedes vitriolic particles. Because the calces of metals differ more, in their density, from air, than metallic salts differ from that fluid. Therefore, each *molecula* of air, which intercedes the metallic particles, powerfully reflects a white light, and consequently is itself a minute white body, such as is seen in the globules of air enveloped in the small bubbles of water which constitute white froth.

But, as the specific density of metallic calces greatly exceeds the specific density of water, the *moleculæ* of air, which intercede the metallic particles, reflect the light stronger than those which intercede the aqueous particles, in proportion to their difference of density with respect to that of the ambient substances, whose vacuities they occupy.

No

No substances, whose interstices are occupied by air, differ more from air, in their specific density, than metallic calces do. For which reason, the reflections made at the surfaces, which intercede those media, are extremely strong.

The Light, reflected from the *moleculæ* of air contained in the interstices of metallic calces, is transmitted through the thin Transparent Matter of the calces which cover them, and is thereby tinged, according to their respective colours.

It is evident that calces, obtained from Transparent Metallic Solutions, by the evaporation and expulsion of their aqueous, and saline, parts, consist of Transparent Matter: for, the metallic particles in the solutions, and in the calces, are the same, and the opacity, or transparency, of the solutions, and calces, arise from the difference of the media, which intercede the metallic particles in the one, or the other, of those states.

Calces, united with pellucid colourless glass, are transparent; and metallic glassess, which are formed by fusion of the calces, are also transparent. For they constitute solid, smooth, masses, devoid of such pores as are capable of admitting the entrance of air.

* The existence of air, in the calces of metals, is clearly established by numerous chymical experiments. From these it appears, that metals, during their calcination, copiously absorb the
ambient

ambient air, and thereby acquire a considerable increase of weight. When they are again reduced to their metallic form, a quantity of air, equal to that which was acquired during the calcination, is disengaged, and the mass loses the adventitious weight, which it possessed during its calciform state.

Metals, calcined by heat only, act upon light in the same manner as those which have been previously dissolved, and afterward calcined. They agree, in the discontinuity of their particles; in their absorption of air, and their consequent increase of weight; and in their transparency, which is manifested, when they are mixed with pellucid glass, or other pellucid media, and when transparent metallic glasses are produced by their fusion.

Metallic precipitates, which are combined with some of the matters, by which they were dissolved, or precipitated, transmit the light which is reflected by those matters. When precipitates are disengaged from such extraneous parts, by ablution, calcination, or any other means, they are mere calces, such as have been already considered.

When oil, instead of air, is interposed between the particles of paints which are formed of the denser metals, such as vermilion, and minium, their colours are not perceptibly altered: because, although oil considerably exceeds air, in
its

its specific density, yet as it differs greatly in that respect, from the denser metallic powders, the moleculæ of oil, which intercede their particles, act upon the incident light so strongly that the reflections, effected by them, cannot be distinguished from those which are caused by rarer media.

When ochres, and other paints, which owe their colours to the rarer metals, are combined with oil, they assume a darker hue. Because the excess of the density of oil, over that of air, forms a sensible difference, when comparatively considered, with respect to the specific gravity of the rarer metals. From this cause, perceptibly less light is reflected from the moleculæ of oil, than from those of air, and consequently the mass appears darker.

When air is expelled from, and oil is united with, coloured powders, whose specific density is much less than that of metallic calces, the brightness of their colours is diminished in proportion as the powders approximate, in specific density, to the media which occupy their interstices. And when the specific density of these is nearly equal, there is no sensible reflection in the confines of their respective surfaces, and therefore the mass appears black.

Thus, when indigo, and other transparent vegetable paints, are united with oil, the air is thereby expelled from their interstices; and the
oil,

oil, which is admitted in its stead, from the nearness of its density, to that of the ambient powders, reflects no sensible light, so that the mass, which consists of such uniformly dense media, is black.

When smooth surfaces of dark-coloured marble, or slate, or of any other polished coloured substances, are scratched, the air enters into the interstices which are opened by this operation, and according to the excess of its rarity, over that of the masses whose particles it intercedes, it strongly reflects a whiter, or lighter-coloured, hue. But, when by polishing the surface, or filling the pores with a denser medium, the air is removed from them, the darker hue is restored.

From all the preceding experiments and observations, it appears that vegetable, animal, and mineral Coloured Matter is transparent; that it does not reflect colours, but exhibits them by transmission only; that Opaque Coloured Bodies consist of transparent matter, which covers opaque white particles, and transmits the light, which is reflected from them.

I shall, in the next place, examine the nature of Semipellucid Coloured Substances, which appear of one colour, when viewed by incident light, and of another, when viewed by transmitted light: and I shall endeavour to shew, from several experiments and observations, that, in these, as well as in Opaque Coloured Bodies,

no reflection is made by Coloured Matter, but by White, or Colourless, Particles only.

Semipellucid Substances, which appear of one colour when viewed by incident light, and of another colour when viewed by transmittted light, consist of pellucid media, throughout which White, or Colourless, Opaque Particles are diffused.

The opaque particles are disposed at such distances from each other, that some of the incident rays of light are capable of passing through the intervals which intercede them, and thus are transmitted through the semipellucid mass.

Some sorts of rays penetrate through such masses, whilst other sorts, which differ from them in their refrangibility, are reflected, by the White, or Colourless, Particles, and from thence are transmitted back through the pellucid part of the medium, which intervenes between the reflecting particles and the anterior surface of the mass.

When pellucid colourless glass is melted with arsenic, the arsenic is thereby divided into minute opaque white particles, which are equably diffused throughout the glass. If only a small quantity of arsenic is used in this compound, the white particles are rarely diffeminated in it.

When glass, thus combined with a small proportion of arsenic, is held between the window and the eye, it appears Yellow or Orange

F

Coloured.

Coloured. When it is viewed by incident light, it exhibits a Blue Tinge. The yellow, or orange colour arises from the transmission of the less refrangible rays, from whose mixture that colour results. The more refrangible rays are not transmitted through the glass, but are reflected by the white particles, and pass back through the Transparent Medium, which is between those particles and the anterior surface of the glass.

I shall here cite from Sir Isaac Newton, a passage,* from which it appears, that from the mixture of those rays, which are transmitted, a yellow, or orange colour must be produced; and that those rays which were intercepted, and reflected, must compose a blue colour.

As the arsenical particles are equably diffused throughout the glass, with which they are combined,

* The letters R, and ρ , refer to a figure in Sir Isaac Newton's Optics (L. I. Part II. Prop. VIII. Probl. III.) which represents the rays of light, cast on a white paper after they have been refracted through a prism, and expresses the compound colours which result from the several mixtures of the differently refrangible rays. The following extracts relate to such mixtures of the rays, as produce blue, and orange colours.

“ At R, where the violet-making, indigo-making, blue-making, and one half of the green-making rays are mixed, their colours must compound a middle colour between indigo and blue.

“ At ρ , the mixture of red, orange, yellow, and one half of the green, must compound a middle colour between orange and yellow.”

bined, consequently the spaces, which intervene between those particles, are equal to each other: and the space also which intervenes between the surface of the glass, and the arsenical particles which are nearest to the surface, is equal to the intervals which intercede the particles. And this may be farther shewn, by breaking such masses of glass; for, the fresh surfaces of every fragment will appear similar to the original surface of the whole mass.

From hence it is evident that, when a smaller portion of arsenic is mixed with glass, the intervals between the White Opake Particles will be larger, and therefore, the less refrangible rays will be more copiously transmitted through them: and, in consequence of their loss, the more refrangible rays which are intercepted, and reflected, by the particles of arsenic, will exhibit a bluer colour, and recede farther from whiteness.

This observation is confirmed by experiment: for, although glass, which contains a small proportion of arsenic, appears blue by incident, and orange coloured, by transmitted light; if a large proportion of arsenic be combined with the glass, the compound, viewed by incident light, appears white, and no colour is transmitted through it, except it be made extremely thin. For, as the intervals between the particles, which are thus densely disposed throughout the glass, do

not admit the passage of the less refrangible rays, they are not separated from the more refrangible rays, but are conjointly intercepted and reflected, by the white particles, which are contiguous to the anterior surface, and therefore the mass appears white.

When a bright light, such as the sun, or the flame of a candle, is viewed through a thick mass of such glass, so many of the more refrangible rays are intercepted, that the transmitted rays compound a Red Colour.

The glass, of which bottles are usually made, affords another instance of a semipellucid substance, which exhibits a blue colour by incident, and a yellow or orange colour, by transmitted light.

This sort of glass, when in its perfect state, transmits a green colour, which it owes to the iron contained both in the vegetable ashes, and in the sea sand, which enter into its composition.

The flux, by which the materials of this glass are fused, is so loosely connected with them, that it is disengaged by exposure to a red heat. In proportion as the glass is decomposed, by the loss of its flux, the earthy particles, which are no longer dissolved, become Opaque. If the glass be withdrawn from the fire, whilst only a small part of the flux is disengaged, the mass consists of Transparent Glass, throughout which the opaque earthy particles are disseminated.

If

If the glass be surrounded with white sand, or other earthy substances, and exposed to a greater heat, it entirely loses its transparency, and texture, and assumes the appearance of porcelain or earthen ware, as M. Reaumur first observed. I have continued this process so far, that the whole of the flux was disengaged from the other materials of the glass.

After having exposed, in a strong, continued heat, the neck of a bottle, filled, and surrounded, with white sand, I observed that all the flux had quitted the glass, and united with the sand, which had been in contact with its external, and internal, surfaces. For the space, which had contained the glass, was occupied by a loose sandy powder, and on each side of that space, the white sand was united into a firm, consistent, mass, which represented a mould, whose cavity was of the exact form, and size, of the neck of the bottle, from whose flux it received its shape, and consistence.

When the glass, from the degree of heat, to which it has been exposed, is reduced to such a state, that it consists of a Transparent Medium, mixed with Opaque White Particles, it exhibits a blue colour by incident light, and a yellow, or orange colour, by transmitted light. For, the more refrangible rays being intercepted and reflected by the white earthy particles, pass back through the space, which intervenes between

those particles and the anterior surface of the glass; by which a blue colour is compounded. And the less refrangible rays, pervading the semipellucid medium, compound a yellow, or orange colour, as has been already explained, with respect to the glass combined with arsenic.

When a greater degree of heat is applied to the glass, by which the opaque earthy particles become more copious, the mass appears almost white. Because, as in this dense state of the opaque particles, almost all the differently refrangible rays are intercepted, and reflected, by them, a hue nearly approaching to whiteness arises from their mixture.

The quantity of ferruginous particles, in this mass, is so inconsiderable, and the colour produced by them is so diluted by the numerous reflections from the white opaque particles, that it becomes almost imperceptible.

The atmosphere acts upon the rays of light, in the same manner as the semipellucid media which have here been described.

The blue colour of the sky is not produced by reflection from the atmosphere, considered as an uniform extended mass. For such a mass would reflect the colour, from its surface. As reflections are made only at the surfaces of bodies, which differ, in density, from the media, which are contiguous to them; but the atmosphere does not reflect any coloured light from its surface.

Thus,

Thus, when the air contained in a chamber, or in a court or area, is viewed through a glass window, the surface of the atmosphere, which is contiguous to the glass, reflects no colour, but is pellucid and colourless. Nor is any colour reflected by the surfaces of air, which are adjacent to water, crystal, or any other media, placed in contact with it.

The air contains a great variety of extraneous particles, which although they are almost, or entirely, imperceptible when separate, yet, when viewed collectively, are capable of producing visible reflections, by their united powers.

When a beam of light is admitted through a small hole, into a dark chamber, innumerable motes are seen floating in the air, which is thus illuminated. These minute bodies vividly reflect a white light around them, in every direction, so that they are distinctly seen from every part of the dark chamber. Such particles occupy all parts of the air which have been hitherto observed.

The atmosphere abounds in volatile, and evaporable matters, which are disengaged from natural bodies, by several operations, as fermentation, effervescence, putrefaction, the action of fire in volcanos, and various other means of decomposition.

Many of the particles, which are separated by such processes, differ considerably, in density,

from the air. And, as they are, for the most part, colourless, they reflect a white light, and therefore may be considered as white particles, diffused throughout the pellucid colourless air.

In this respect, the atmosphere is similar to the semipellucid medium, which is formed by diffusing the white particles of arsenic, throughout pellucid colourless glass. In both these substances, whilst the white, or colourless, particles are rarely disseminated through the transparent medium, the less refrangible rays are transmitted through the intervals which intercede the particles, and compose an orange, or red, colour : but, the more refrangible rays are intercepted, and reflected, by the particles, and the mixture of those rays produces a blue colour.

In the air, as well as in the solid semipellucid media, when the white particles are more densely arranged in the pellucid medium, the intervals which intercede them are diminished, and the distance, between the surface of the pellucid medium, and the white particles, is also reduced.

In this state of the atmosphere, as the greatest part of the yellow, orange, and red rays, are intercepted, and reflected, together with the more refrangible rays, they, by their union, exhibit a hue nearly approaching towards whiteness.

When the part of the atmosphere, which is near the surface of the earth, is occupied by
gross

gross vapours, this mixture of air with aqueous, or other particles, is white : and, the anterior surface, as well as the interior parts, of the compounded medium, appears to be densely stored with white particles. Fogs, which consist of gross vapours, seem chiefly to differ from clouds, in their depression, and contiguity to the surface of the earth.

When such vapours are elevated higher in the air, and form clouds, they reflect the white light of the sun, and thereby appear white, whenever its incident rays fall upon them intire and undivided.

As the reflective particles are not equally diffused through every part of the pellucid air, of which the atmosphere principally consists, it frequently happens, that large tracts of air are furnished with only such a portion of subtile contents, as qualify them to reflect a blue colour ; whilst others are so densely stored with reflective particles, that they constitute clouds.

The inferior parts of the atmosphere which are adjacent to the surface of the earth, constantly abound in dense exhalations, more than the higher regions.

Naturalists have not hitherto obtained any considerable insight into the nature, and origin, of the particles by which the transparency of the air is impaired, except as far as relates to
aqueous

aqueous meteors. It is certain that some of the most extensive, and permanent vapours, which have been observed in the atmosphere, were not formed of aqueous or humid matter.

The mist, which obscured the air, during the summer of the year 1783, was remarkable for its extent. For, it involved almost all Europe, a part of Asia, and of Africa, and perhaps reached much farther: its altitude was so great, that the Alps were immersed in it.

In most parts of Europe, the air, during the prevalence of this vapour, was unusually dry. For, the hydrometer did not rise to the point which denotes moisture; salt crystallized in brine pits, before the ordinary period; and other processes, which depend upon evaporation, were accelerated.

Several other curious observations, relative to this subject, are contained in an account written by M. Senebier of Geneva.*

When the air is replenished with very dense vapours, it transmits only the less refrangible rays, from whose mixture an orange, or red, colour is produced. Distant mountains covered with snow, clouds, or other white substances,

* The paper of this excellent philosopher is inserted in the Journal of the Abbé Rozier (Anno. 1784. May.) The same collection contains also instructive accounts of that subject by M. Toaldo, Professor at Padua, M. Lamanon, and M. Marcorelle, Baron d'Escalle. (Jan. 1784.)

which

which are opposed to the rays transmitted through the atmosphere, reflect their light, and thence assume their colours.

Sir Isaac Newton attributed the various colours of the clouds, to the different magnitudes of the particles, whereby he conceived that they were qualified to reflect the differently refrangible rays. M. Melvill has more accurately remarked, that the colours of the clouds, at sun-rising and setting, do not depend on the sizes of their component particles, but arise merely from the colours of the rays transmitted through the tract of air which is contiguous to the horizon, and that they indiscriminately reflect the rays which are incident upon them.

This observation perfectly agrees with the phenomena. But the author of this remark does not seem to have formed any clear or precise conception of the constitution of the atmosphere, and its action on the rays of light. He supposed, that the atmosphere is similar to Transparent Coloured Liquors.* But, it

* *Physical Essays*: Edinburgh. 1756. vol. II. p. 79.
“ To understand why the sun's rays, by passing through a
“ greater and greater quantity of air, change by degrees
“ from white to yellow, thence to orange, and lastly to
“ red, we have only to apply to the atmosphere, what Sir
“ Isaac Newton says (Book I. of his Optics, Part II. Prop.
“ X.) concerning the colour of transparent liquors in
“ general.”

appears

appears from several parts of this inquiry, that Transparent Coloured Liquors do not reflect any colour, but appear black when viewed by incident light: therefore, the atmosphere, which exhibits colours by reflecting the incident light, does not, in its optical properties, resemble such liquors.

Mr. Melvill not only acquiesces in the general opinion, that colours are produced by the reflection of the several rays, from the Colouring Particles: but he extends his doctrine of the reflective power of those particles, so far as to attribute to them the action on light, whereby opaque bodies are sooner heated by the sun-beams, than transparent ones. "As (according to him) each *colorific particle* of an opaque body, by the reaction of the particles of light, must be somewhat moved, when the light is *reflected* backward and forward between the same particles, it is manifest, that they likewise must be driven backward and forward with a vibratory motion."*

With respect to this hypothesis, I shall only observe, that, as the Colouring Particles of bodies do not reflect the rays, but appear black by incident light, even when contiguous to air; they cannot, according to any optical law, exercise a reflective power, when they are in contact with the internal parts of media, whose density

* Ib. p. 20.

greatly

greatly exceeds the density of air, and thereby approaches much nearer to that of the colouring matter itself.

When distant objects are seen, through a considerable tract of such rare air as constitutes a blue sky, those objects assume the blue colour of the air. For they must be considered as reflective bodies, acting on the incident light, in the same manner as the reflective particles, which are diffused through the air. So that the reflected light passes back, from them, mixed with the blue rays, which are reflected by the minute extraneous particles of the atmosphere.

If a denser atmosphere, or a longer tract of it, intervene between the objects and the eye, they become fainter and less distinct, and appear whiter; as the rays reflected from them are mixed with the whiter hue, which numerous particles communicate to the air.

By the interposition of a still greater quantity of the reflective particles of the air, the objects disappear. For the weak reflected light of distant objects, cannot, like the strong light of luminous bodies, penetrate semipellucid substances, so as to transmit through them even the less refrangible rays.

These, and all the phenomena of the atmosphere, may be imitated, and explained, by artificial semipellucid substances, such as have been here described.

Sir

Sir Isaac Newton, and others, have supposed that the green colour of the sea is produced by the reflective power of the water. But, actual observations do not confirm, or agree with this opinion.

When sea water is admitted into a reservoir, which does not exceed a few inches in depth, the water appears pellucid and colourless. It is therefore manifest, that no colour is reflected from its surface. Consequently, the water of the sea, considered as an uniform extended mass, does not reflect any colour.

Sea water abounds in heterogeneous particles. Magnesia is procurable from its analysis: calcareous earth may be obtained in the same manner, and manifests itself in the numerous shells, corals, and other calcareous concretions, which are formed in it. The strata, which compose the bottom, and shores, of the sea, also furnish various saline, metallic, bituminous, and other matters. The animals, and vegetables, which it nourishes, contribute to the production of extraneous particles. All these receive an addition from the rivers, which constantly discharge their contents into the sea.

Many of the earthy, and other, particles accede, in density, so near to water, that, when they intercede that medium, their reflective power must be very weak: but, as they do not entirely coincide with water, in density, they must

must be endued with a small degree of reflective power. Therefore, although they may be invisible, when separately viewed, yet when the forces of a great number of such minute bodies are united, their action on the rays of light becomes perceptible; some sorts of rays being reflected by them, whilst others are transmitted through their intervals, according to the quantity of reflective matter, which the rays arrive at, in the internal parts of the water.

The opacity of the sea, caused by the numerous reflections from its internal parts is so considerable, that extensive masses of it cannot be seen through: even although the obstacle arising from the colourless light, reflected from its surface, be removed, by viewing the lower part of the water, through a dark tube immersed under the surface, at the bottom of which a polished glass plate is joined.

The nature and origin of the particles, which diminish the transparency of the water of the sea, have not hitherto been examined, except as far as relates to the more obvious saline, and earthy, substances which are commonly obtained from its analysis.

Yet, although the matter, of which these particles are formed, is not ascertained, it is certain that they are endued with a somewhat greater reflective power, than those which are suspended
in

in the atmosphere, when in its rarest state. For the reflective particles, of the rarest sky, exhibit a blue colour, when viewed by incident light; but the reflective particles of the sea act upon a greater portion of the more refrangible rays; whereby they exhibit a green colour; and, (as Dr. Halley found from actual observation) transmit a rose colour, which is red, inclining to violet, at such depths as only the less refrangible rays can penetrate.*

Sir Isaac Newton observes that those parts of thin plates of water, or air, which by transmitted light appear of a colour compounded of red and

* Newton. Opt. L. I. Part II. Prop. X. Probl. V.
 "Of this kind, is an experiment lately related to me by
 "Mr. Halley, who in diving deep into the sea in a diving
 "vessel, found in a clear sun shine day, that when he was
 "sunk many fathoms deep into the water, the upper part
 "of his hand, on which the sun shone directly through the
 "water, and through a small glass window in the vessel,
 "appeared of a red colour, like a damask rose, and the
 "water below, and the under part of his hand, illuminated
 "by light reflected (*) from the water below looked
 "green." (*) All the green light, by which the under
 part of the hand was illuminated, was not reflected from
 the medium, which was beneath the vessel: for, a part of
 it was reflected from the ground, over which the vessel was
 placed. The light, thus reflected from the ground, was
 tinged green, by passing through the small depth of water,
 which intervened between the ground, and the vacant space
 in the vessel, under the hand: whereby the rays, reflected,
 from the ground, were mixed with the green rays reflected
 from the internal parts of the sea water.

violet,

violet, exhibit a green colour by reflected light.* These he calls opposite colours, by which term he usually expresses those transmitted colours which are seen in the part of the medium, which is opposite to the reflected colours, and *vice versa*.†

All colours, transmitted by semipellucid substances, are opposite to those which the substances exhibit when viewed by incident light. And in proportion as Transparent Coloured Media grow opaque, by the formation, or reception, of white, or colourless particles, the colours which they transmit recede farther and farther from the original colour, which the medium transmitted whilst it was transparent, until at last the mass grows so opaque, that no rays are any longer transmitted.

I shall not enter upon any farther explanation of the manner in which the water of the sea acts upon the rays of light, as the observations which have been made respecting the air, and other semipellucid media, are likewise applicable to the optical appearances of the sea.

The semipellucid substances, which I have hitherto described, reflect the more refrangible,
and

* Ib. Prop. V. Theor. IV. Exp. X. "If the red and violet be intercepted, the remaining yellow green and blue, will compound a green."

† Ib. L. II. Part I. Obs. IX. "By looking through the two contiguous object glasses, I found that the inter-
G "jacent

and transmit the less refrangible rays. Such media, for the most part, act upon the rays in a similar manner.

The reflection, and transmission, of the more or less refrangible rays, depend upon the powers of the reflective particles. The reflective, as well as the refractive, power of bodies being in a great measure proportionable to their specific gravity.

Instances rarely occur either of natural, or factitious semipellucid substances, in which the reflective particles are of so great a specific gravity, as qualifies them to reflect the less refrangible rays, such as red, or orange; and, which at the same time are so minute, and so rarely diffused, that intervals are left between them, sufficient to admit the passage of the rays.

The specific gravity of gold is much greater, than that of any other known substance, by which glass can be equably tinged. I therefore,

“jacent air exhibited rings of colours, as well by transmitting light, as by reflecting it.

“I found that white was opposite to black, red to blue, yellow to violet, and green to a compound of red and violet. That is, those parts of the glass were black when looked through, which when looked upon appeared white, and on the contrary. And so those which in one case exhibited blue, did in the other case exhibit red, and the like of the other colours.”

judged

judged it expedient to examine in what manner the particles of that metal, combined with glass, would, under various circumstances, act upon the differently refrangible rays.

For this purpose, I combined gold with pellucid colourless glass, after the manner of Kunckel, Cassius, and others, by which a Transparent Coloured Glass was composed, which transmitted a bright red colour, but appeared black by incident light.

I exposed several pieces of this red glass to the heat of burning coals; by which means, they lost their transparency, and underwent an alteration in their texture. For, when the red glass is thus reheated, the particles of gold, uniting with some of the other ingredients of the glass, form Opaque Moleculæ, which reflect all the rays, excepting the violet, and thereby appear by incident light, of a light brown hue.

If all the rays were equally reflected, the mass would appear white, when viewed by incident light. But, the privation, of even a small portion of them, impairs the whiteness, and reduces it to a brown hue, which is lighter, or more intense, as a greater or less quantity of the different rays are wanting in its composition.

The brown hue, reflected from the glass, which is here instanced, arises from the white light reflected from the Opaque Particles, to which a small proportion of all the rays, excepting the violet, is superadded.

The violet rays are transmitted through the glass, and, therefore, it appears vividly tinged with a violet colour, when looked through.

In proportion as the transparency of this red glass is impaired, the transmitted colour recedes from red, till it becomes violet: according to the law which all Transparent Bodies observe, when Opaque Particles are introduced into, or formed in them, so as to render them semipellucid.

This experiment manifests the strong reflective power, with which the particles of gold are endued, according to their specific gravity.

In this kind of glass, and in all other Semipellucid, as well as Opaque, Coloured Substances, colours are reflected from White, or Colourless Particles only, and are transmitted through the Transparent Parts of the Media.

It is not necessary to extend this subject, by a description of Semipellucid Liquors, as they act according to the same laws and afford the same appearances, as the solid media, which have been already instanced.

In the preceding experiments, I have preferred the use of semipellucid glasses, because they are not apt to be decomposed, or suffer any variation in their texture; and therefore are disposed, constantly, and equably, to exhibit the same colours.

The coloured light, which is transmitted through Semipellucid Substances, passes through the intervals

tervals which intercede the Opaque Particles diffused through them. For, when the Opaque Particles are so densely arranged, that they intersect, and cover, the interstices which lie between them, the passage of the rays is obstructed, and none of them are transmitted: but, the mass ceases to be semipellucid, and becomes opaque.

The same cause of obstruction to the passage of the rays takes place in Transparent Coloured Bodies, when the Colouring Particles are densely arranged: so that the light is intercepted and absorbed, by the colouring matter, and the mass, consequently, appears black, in whatsoever direction it is viewed.

From several experiments, and observations, which I have made, in the course of this inquiry, it appears, that the rays of light are transmitted through Transparent Coloured Substances by means of a power, with which they are endued; and, that those Media transmit Coloured Light with the greatest strength, which have the greatest refractive power.

The strong refractive, and reflective, power of inflammable bodies has been observed by Sir Isaac Newton. But, the power, of such bodies, to transmit the rays otherwise than by refracting them, has not, I believe, hitherto been noticed.

The following experiments prove, that the Transmissive Power, of Inflammable Coloured Media is much stronger, than the Transmissive

Power of Coloured Media, which do not abound in phlogistic matter.

To a dilute solution of green vitriol in distilled water, I added a small quantity of an aqueous infusion of galls. The liquor, composed of these ingredients, transmitted a blue colour, which, although perfectly distinct, and unmixed with any other hue, was not vivid, but appeared as a coloured substance not acting upon a sufficient quantity of the rays of its own colour.

I made a tincture, by digesting green vitriol in spirit of wine, and, to a portion of this tincture, diluted with a farther addition of spirit of wine, I applied a small quantity of a strong spirituous tincture of galls. This liquor, thus prepared, transmitted a blue colour, greatly excelling in beauty and brightness.

The strength, of the transmissive power of inflammable media, is manifest from a comparative view of these processes, and others which have been already instanced.

Sir Isaac Newton attributed the colours of natural bodies, to the several sizes and densities of their particles, by which, according to him, they *reflect* several sorts of rays, and thereby appear of several colours.

It has been shewn, throughout this inquiry, that the Colouring Particles are not endued with a reflective power, but produce their several colours by transmitting the several sorts of rays.

The

The experiments, made with thin plates of glass, water, and air, from which Sir Isaac Newton inferred, that the several colours of natural bodies arise from the several sizes and densities of the particles, were executed with so much skill and precision, and have been so often successfully repeated, by later inquirers, that they are firmly established.

But, the doctrine of a reflective power existing in the Colouring Particles, does not appear to be deducible from those experiments, nor is it conformable to any subsequent observations.

Sir Isaac Newton observed, that thick plates of glass yield* rings of colours, in the same manner as the thin plates, from whose appearances he deduced this explanation of the colours of natural bodies.

The Duke de Chaulnes has proved, that none of the colours, exhibited by such thick plates, are reflected by the anterior surface of the glass; but that the rays, after having passed through the first surface, to the farther surface, are thence reflected back.†

May it not from hence be inferred, that, since the action of thick plates, in exhibiting colours, is analogous to that of thin plates, the colours, even in these, are not produced by reflection from the anterior surface, but by a remoter reflection,

* Newton. Opt. L. II. Part IV.

† Acad. Paris. Ann. 1755. p. 136.

and by a subsequent transmission through the pellucid glafs.

From all the experiments, which I have here adduced, it uniformly appears, that no Coloured Light is reflected from the anterior surfaces of Opaque, Semipellucid, or Transparent Coloured Bodies. For, in these, the light is reflected by the superficies which intercedes the transparent part of the medium, and the substance which is behind it: and the light, thus reflected, is transmitted back, through the transparent part of the medium, which intervenes between the reflective surface, and the anterior surface.

In these respects, the Coloured Media, which have been examined throughout the course of this inquiry, agree with the plates of glafs observed by the Duke de Chaulnes.

If the experiments, which have been made with thin Transparent Colourless Substances, and those which have been performed with Coloured Media, be jointly considered, it will appear that the effects, which Sir Isaac Newton has attributed to Reflected Light, should have been applied to Transmitted Light. And the observation of this great philosopher, relative to the connection between the colours of natural bodies, and the size and density of their particles, if thus modified, will coincide with his own experiments, and all the others which have been made subsequent to them.

In

In a former work, I have shewn by a series of experiments, that the changes of colour, which Permanently Coloured Substances undergo, are made in a regular order, accordingly as the sizes of their colouring particles are diminished, or augmented.

I have here adduced some examples of the influence of density and of phlogiston, on the colours of the bodies.

Besides these means, by which the colours of some substances are affected, I have frequently observed that there is another cause, by which changes are produced in Transparent Coloured Media, not only in the *degrée*, but also in the species of the colour.

These changes arise from the greater, or less obstruction which the rays meet with, in their passage through the interstices which intercede the Colouring Particles; according to the thicknesses of the media, and the quantity of colouring matter diffused through them.

Transparent Coloured Media act upon the rays of light, more simply and uniformly, than Semipellucid Substances: because, in these a greater variety of phænomena result from the different forces of the Opake Particles: by which some of the rays are reflected, whilst others are transmitted.

Although all Transparent Coloured Media transmit a less quantity of the incident rays,
in

in proportion as the passage through their interstices is obstructed; some of those media, during the decrease of their transmitted light, do not vary the species of their colour: but, in other Transparent Coloured Media, the transmitted colours are changed, by the resistance to which the rays are opposed, during their passage through the interstices.

The changes, which are thus effected in Transparent Coloured Media, generally proceed in one and the same order. So that, in proportion as the passage of the more refrangible rays, through such substances, is obstructed, the less refrangible rays, by their greater momentum, penetrate the medium and are transmitted through it.

From the mixture of the less refrangible rays, which are thus transmitted, the mass exhibits either a red, or some colour inclining to red, in proportion as a greater or less quantity of the more refrangible rays are intercepted.

It is probable, however, that some instances may be found, of media whose changes of colour do not coincide with this general rule. Especially, if such media owe their colours to phlogistic matter, or to particles which differ greatly in density, from the pellucid part of the substances through which they are diffused.

I have not met with any observations, relative to the changes of colour, arising from the
cause

cause which is here considered, excepting such as relate to yellow liquors, which are apt to transmit orange, and red colours, in proportion as the rays are transmitted through greater thickneses of such media.

Sir Isaac Newton, in the following passage, has attributed, to red liquors, the property of transmitting these colours, according to the different thickneses of the liquors. "A red liquor "in a conical glass held between the light and "the eye, looks of a pale and dilute yellow at "the bottom where it is thin, and a little higher "where it is thicker grows orange, and where "it is still thicker becomes red, and where it is "the thickest the red is deepest and darkest."*

The liquor, which was the subject of this observation, was, probably, an aqueous or spirituous infusion of some of the woods which are used in dying red. For, these transmit a yellow, orange, or red colour, according to their thickneses, or tenuity.

But, red liquors do not transmit orange, or yellow, colours, even when spread thin. Several red liquors are enumerated in the table p. 22, such as the nitrous solution of cobalt, the red infusions of flowers, the red juices of fruits, and berries; and several others. When these liquors are disposed in thicker, or thinner, masses, they

* Newton. Opt. L. I. Part II. Prop. X. Probl. V.

do not vary the species of their colour, but only transmit a diluter, or more intense red.

Nor do red glasses appear yellow, or orange, when divided into the thinnest plates.

These Transparent Red Media, from the interception of the transmitted rays, suffer no other change, except the diminution, or loss, of their colour, whereby they assume a darker hue, or become black.

As the changes of colour, thus effected in yellow liquors, have been already observed, I shall not mention any experiments relative to them, but shall advert to other media, whose phenomena have not, I believe, been hitherto noticed.

I digested, in spirit of wine, a sufficient quantity of sap green, which is an expressed vegetable juice, inspissated, and dried. When the spirit of wine was saturated with this colouring substance, it was filtered through paper, and afterwards poured into a small flint-glass bottle which was of the form of a wedge, or triangular prism.

That portion of the coloured liquor, which was contained in the angular part of the bottle, and which, consequently was the thinnest, transmitted a vivid green colour; that portion, which was in the widest part of the bottle, transmitted a bright red colour; the intermediate portion, which was between the green and the red, transmitted a yellow colour: but the yellow

was

was much inferior to the two other colours, both in quantity, and brightness. The liquor, when viewed by incident light, appeared black.

Sap green infused in distilled water, and viewed in a similar bottle, transmitted the same colours. But, the green was not so copious, or so vivid, as in the spirituous tincture; and the proportion of the yellow was likewise diminished.

These experiments afford a farther instance of the superior transmissive power of inflammable media; since the more refrangible rays are more copiously, and more vividly, transmitted by the spirituous tincture, than by the aqueous infusion.

By infusing grass, and other green leaves, in spirit of wine, I obtained a tincture, consisting of the spirit of wine saturated with the colouring matter of the leaves. This was examined in the same manner as the preceding liquors: it transmitted a bright green, where it was thinnest; and a vivid red, where it was thickest: but, the intermediate yellow was scarcely perceptible. This, as well as the two former liquors, appeared black, when viewed by incident light.

I infused litmus in distilled water, and having thus procured a coloured infusion, I filtered it, and examined it, in the same manner as the liquors, which have been already described. This infusion transmitted an azure blue colour, where it was thinnest; and a bright red, where it was thickest. The intermediate colour was purple. This li-

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quor also appeared black, when viewed by incident light.

When these liquors are sufficiently diluted, each of them transmit the more refrangible rays, even when they are contained in the widest part of the prismatic bottles. For, the greater thickneses of diluter coloured liquors, contain no more coloured particles, than thinner masses, which are more intensely coloured.

These phænomena seem to indicate, that the power, by which the several rays of light are transmitted through Coloured Media, is inherent in the Colouring Particles themselves, and therefore, is not confined to the surfaces of such media. For, if the transmissive force was exerted at the surfaces only, thinner plates of Coloured Substances would act upon the rays, as powerfully as thicker masses. But, it appears, from experiment, that, in proportion as the rays pass through different thickneses of coloured media, they exhibit colours, differing, not only in degree, but, frequently, in species also.

The sun's light, by which bodies are illuminated, consists of all the rays, by which a white light is compounded. These rays, in their entire and undivided state, are incident upon the Opaque Particles of Semipellucid Substances; and, upon the Colouring Particles of Transparent Coloured Substances, whenever those media are exposed to the light.

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When the rays accede to the opaque particles of semipellucid substances, some sorts of them are reflected back, from the anterior surface of those particles: the other sorts of rays, which are not reflected back, are diverted from the direction which is opposite to the anterior surface of the opaque particles, and, passing through the intervals, between the particles, are transmitted through the mass.

When the rays are incident upon the particles of Transparent Coloured Bodies, none of them are reflected back, because the colouring particles are not endued with any reflective power. But, some of the rays are either stopt at the anterior surfaces of the particles, or are diverted into such directions, as render them incapable of passing towards the farther side of the mass, and, consequently such rays cannot be transmitted. The rays, which are not thus intercepted, or dispersed, are transmitted, in the same manner as those which pass through semipellucid media.

Thus it is evident, that the coloured rays, which are transmitted through semipellucid substances, are *inflected* by the Opaque Particles: and those which are transmitted through Transparent Coloured Substances, are *inflected* by the colouring particles.

I have already shewn, that those media transmit coloured light with the greatest strength, which have the greatest refractive power. From the preceding

preceding observations, it appears, that the particles of coloured media inflect the several sorts of rays, according to the several sizes, and densities, of the particles; and also, in proportion to the inflammability, of the media which owe their colour to them: and it is manifest, that the transmission of coloured rays depends upon their inflection.

All these observations are conformable to Sir Isaac Newton's doctrine, that the rays of light are reflected, refracted, and inflected, by one and the same principle, acting variously in various circumstances.

I have hitherto investigated, and explained, the powers and operations, by which the rays of light are transmitted through coloured media; and, have shewn that, in Opaque Coloured Bodies, they are reflected by the opaque particles, which are constituent parts of such bodies, and, that the light, thus reflected, passes back through the Transparent Colouring Matter, with which the opaque particles are covered.

It appears, both from the analysis of Opaque Coloured Bodies, and from several other experiments and observations, that the matter, by which they reflect the light, consists of white particles.

The solid parts of animals, and vegetables, are principally composed of calcareous earth, which is a perfectly white substance. This earth also abounds in the mineral kingdom, as well as the siliceous, and argillaceous, earths, and magnesia, which

which also are perfectly white, when pure, and divested of adventitious matters.

All these earths constitute Transparent Colourless Media, when they are vitrified, together with proper fluxes; or when they are dissolved in colourless menstrea. And the saline masses, which are obtainable from their solutions, are transparent and colourless, while they retain the water which is essential to their crystallization, and are not flawed, or reduced to powder.

But when, by such means, the interstices of those masses are evacuated, or opened, they are rendered white and opaque, by the admission of air, or of a rarer medium.

The earthy particles, which form the solid parts of bodies, generally exceed, in density, the other constituent particles, which they intercede. For, in the composition of bodies, earths are, for the most part, combined with aqueous, ærial, saline, or inflammable matters; all of which are greatly inferior to earths, in their specific density. And, therefore, the surfaces of the earthy particles, which are contiguous to such media, must reflect the rays of light, with a force which is proportionate to their excess of density.

The reflective power of bodies does not depend merely upon their excess of density, but upon their difference of density, with respect to the ambient media. Therefore, Transparent Colourless Particles, whose density is greatly inferior to that of the media which they intercede, also powerfully

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reflect

reflect all the sorts of rays, and thereby become white.

Of this kind are the air, or other rare fluids, which occupy the interstices of liquors; of transparent solid bodies, flawed, or reduced to powder, or otherwise minutely divided; of porous solid substances; of calces of metals; and in general of all denser media, into whose interstices such rarer particles are admitted.

These observations are grounded upon Sir Isaac Newton's doctrine, relative to the transparency, and opacity of Colourless Substances. And from thence it may be deduced, that white opaque bodies are constituted by the union or contiguity of two, or more, Transparent Colourless Media, differing considerably from each other, in their reflective powers.

Such white substances are instanced in froth, emulsions, or other imperfect combinations of pellucid liquors, milk, snow, salts calcined or pulverized, glass, or crystal, reduced to powder, white earths, paper, linen, and even those metals, which are called white by the mineralogists and chymists. For those metals do not appear white, unless their surfaces be rough. Because, the surfaces of polished metals do not afford interstices, into which air, or other rare fluids capable of reflecting light, can be admitted.

But, when interstices are opened on the surfaces of metals, by roughening them, the air occupies those interstices, and its *moleculæ*, according to the

the great difference of their density, with respect to that of the metal, vividly reflect a white light.

The rough surfaces of metals consist of minute irregular prominences, and cavities, from which the rays are reflected, in different directions, whereby they are blended and intermixed, and, by their mixture, constitute whiteness.

But, the polished surfaces of metallic mirrors equably, and regularly, reflect the several incident rays, according to their several angles of incidence: so that the reflected rays do not interfere with each other, but remain separate and unmixed, and therefore distinctly exhibit their several colours.

From hence it is evident, that white surfaces cannot act upon the light, as mirrors: because all the rays, which are reflected from them, are promiscuously, and disorderly blended.

Nor can the surfaces of mirrors appear white, except when white objects are casually opposed to them: because the rays which fall upon them from coloured objects, are reflected separately, and distinctly, whereby colours are exhibited.

In forming ornamental works of silver, artists sometimes avail themselves of the contrast, between the resplendent whiteness of the unpolished parts of the metal, and the regular reflections which are displayed by its polished parts.

White metals are peculiarly adapted to the formation of mirrors, as their surfaces are capable of being polished, by which they are qualified

equably, and regularly, to reflect the incident rays; as their reflective power is proportionate to their specific density, which is very great; and as they are disposed indiscriminately to reflect all the differently refrangible rays.

Mercury, silver, lead, and tin, are pellucid and colourless, when dissolved in their proper menstrua. In the solutions of other metals, some colouring particles are mixed with the colourless particles. The opacity, and the vivid lustre of the entire metals, which consist of those pellucid particles, united with phlogiston, arise from the powerful reflection of the surfaces, which intercede the metals and the air.

Metals do not owe their shining appearance to their metallic particles, but to their phlogiston. For, calcination, which disengages the inflammable principle from metals, deprives them also of their lustre.

The reflective power, of the inflammable principle, is so great, that it imparts, to various pellucid colourless substances, a shining appearance, perfectly resembling the lustre, and hue, of metals.

Plumbago, which has a metallic appearance, and lustre, consists of two substances, which, when separate, are not only pellucid, and colourless, but absolutely invisible. For its sole constituent parts are phlogiston, and fixed air.*

* D. Scheele, in *Aët Stockh.* 1778.

Many marcasites, which scarcely yield to any of the metals, in lustre, do not contain any metallic particles, but consist principally of sulphur, which itself is composed of phlogiston, and vitriolic acid.

Nor is the lustre, and metallic appearance, confined to substances which abound in phlogiston: for, it is exhibited by the surfaces of several Pellucid Colourless Media, which vividly reflect the light; from the difference between their density, and that of the ambient media; from their glossy smoothness or polish; or from various other causes.

Mr. Melvill has clearly explained the silver-like appearance, which drops of water exhibit, when they lie on the leaves of colewort, and some other vegetables. He observed, that the lustre of those drops, is produced by a copious reflection of light, from the flattened part of their surfaces, contiguous to the plant; that the drops, when they have that appearance, do not touch the plant, but are kept at some distance from it, by the force of a repulsive power, or medium, which occupies the intervals between the drops and the leaves: that, as the surfaces of the leaves are considerably rough and unequal, the under surfaces of the drops become rough likewise, and so by reflecting the light copiously, in different directions, assume the resplendent whiteness of unpolished silver.*

* *Physical Essays*: Edinburgh. 1756. vol. II. p. 25.

When Pellucid Colourless Glass is broken, it sometimes happens that, the fresh surface of the fragment is very smooth and glossy. If such a fragment of glass be so placed, that the fresh broken part may be seen at the farther surface, that part cannot be distinguished by the sight, from a similar portion of glass covered with quicksilver.

This effect is produced, by the copious reflection of light from the broken part, which greatly exceeds in smoothness, the original surface of the glass. For, melted glass, from its tenacious consistence, assumes, whilst it cools, a surface less glossy than those which are exposed, by breaking it. Many other like instances may be adduced.

These phænomena afford much insight into the nature, and cause, of opacity. As they clearly shew, that even the rarest Transparent Colourless Substances, when their surfaces are adjacent to media greatly differing from them in refractive power, may thereby acquire a perfect opacity, and may assume a resplendency, and hue, so similar to that of white metals, that the rarer pellucid substances cannot, by the sight, be distinguished from the dense opaque metals. And, this similarity to the surfaces of metals occurs, in the rare pellucid substances, not only when, from the roughness of their surfaces, they resemble unpolished metals in their vivid whiteness; but also when, from their
smoothness,

smoothness, they resemble the polished surfaces of metals.

Metals seem to consist entirely of Transparent Matter, and to owe their apparent opacity, and lustre, solely to the copious reflection of light from their surfaces. The analogy between the metals and Transparent Media, as far as respects their optical properties, will appear from the following considerations.

(1) All metals, dissolved in their proper menstrua, are transparent. (2) By the union of two or more transparent media, substances are constituted, which are similar to metals, in their opacity and lustre, as has been instanced in plumbago, and marcasites. (3) The Transparent Substances of metals, as well as of those minerals, by their union with Phlogiston, acquire their strong reflective powers, from which their lustre and opacity arise. (4) The surfaces of pellucid media, such as glass, or water, assume a metallic appearance, when by their smoothness, their difference of density with respect to the contiguous media, or any other cause, they are disposed copiously to reflect the light.

From all these considerations, it is evident, that opaque substances are constituted by the union, or contiguity, of Transparent Colourless Media, differing from each other in their reflective powers; and, that when the common surface, which intercedes such media, is plane, equal, and smooth, it

reflects the incident rays equally, and regularly, as a mirror: but, when the surface is rough, and unequal, or divided into minute particles, it reflects the incident rays irregularly, and promiscuously, in different directions, and consequently appears white.

As the surfaces of pellucid colourless media are disposed indiscriminately to reflect all the rays of light; so white opaque substances, which are compounded of pellucid colourless media, retain the same disposition, which is indifferent to all the sorts of rays.

It has been already shewn, throughout the course of this inquiry, that coloured matter does not reflect any light; but, that reflective media act indiscriminately on all the different rays. It does not appear from the optical phænomena, which have hitherto been observed, that nature affords any kind of matter endued with a power of reflecting one sort of rays, more copiously than the other sorts. Consequently, no reflective substances are capable of separating the differently refrangible rays, and thereby producing colours.

There are several experiments, and observations, in Sir Isaac Newton's Optics, from which it might have been inferred, that coloured light is not reflected from coloured matter, but from white or colourless matter only.

Although that great philosopher supposes, that all coloured bodies reflect the rays of their own colours,

colours, more copiously than the rest, yet he observes, that “ they do not reflect the light of their
“ own colours so copiously as white bodies do.
“ If red lead, for instance, and a white paper, be
“ placed in the red light of the coloured spectrum
“ made in a dark chamber by the refraction of a
“ prism, the paper will appear more lucid than
“ the red lead, and therefore reflects the red-
“ making rays more copiously than red lead
“ doth.”*

If it be supposed, that the red particles of the minium reflect the red rays, more strongly than the rest, what reason can be assigned, why minium should not exhibit the red rays as vividly as white paper, which acts indifferently on all the rays.

But, if it be considered that, in opaque coloured bodies, the rays, which are reflected from white reflective matter, pass back through the Transparent Coloured Media, with which the reflective matter is covered, it will evidently appear, why the coloured light reflected from white paper, is more copious and bright, than that which is exhibited by red lead.

A considerable part of the incident light is lost, in passing through Transparent Coloured Media. Therefore, the light reflected immediately from the white paper, must be more copious and lucid, than that which has undergone a diminution, in its passage to, and from, the reflective particles

* Newton. Opt. L. I. Part II. Prop. V. Exp. 15.

of the Opaque Coloured Body, through the Transparent Coloured Medium.

When a small portion of colouring matter is mixed with a colourless medium, the mass appears tinged with colour; but, when a great quantity of colouring matter is added, the mass exhibits no colour, but appears black. Therefore, to attribute to colouring matter a reflective power, is to advance an inexplicable and contradictory proposition: for, it is asserting, that, in proportion as more reflective colouring matter is opposed to the incident light, less colour is reflected; and that, when the quantity of colouring matter is very great, no colour at all is reflected, but blackness is thereby produced.

From these arguments, it might have been shewn, that the reflective power does not exist in colouring matter, but in Opaque White Substances only. Nevertheless, in this disquisition, I have not entirely relied on arguments drawn from a few, known and obvious, appearances, but have endeavoured, by numerous experiments, to ascertain the cause of the colours of natural, as well as artificial bodies, and the manner in which they are produced.

M. Euler observed,* that the colours of bodies are not produced by reflection. He supposes that the coloured rays are emitted by the colorific particles. This hypothesis, however, is not agreeable to experiment. For, as the colouring matter

* Acad. Berlin. Ann. 1752. p. 262.

acts upon light, by transmission only, it is evident that bodies do not appear coloured either by reflecting, or emitting the rays.

I have not attended to any other hypotheses, which are unsupported by experiments.

Sir Isaac Newton, and, I believe, all later philosophers, except M. Euler, have attributed to colouring matter a reflective power. And the artists, whose works depend upon the preparation, and use of colouring materials, seem, in general, to have adopted the same theory.

As an instance of this agreement, I have cited, from M. Hellot, one of the most skilful and intelligent authors, who have treated of the Art of Dying, a passage which comprizes his opinion respecting the action of the tinging particles on the rays of light.*

All the other writers, on the same subject, appear to agree in that established opinion: but,

* “ Hellot. *Art de la Teinture des Laines*. 1772. p. 117. Nous ne connoissons, jusqu’ a présent, que deux plantes, qui donnent le bleu, après leur préparation; l’une est l’Isatis ou Glastrum, qu’on nomme Pastel en Languedoc, et Vouede en Normandie; leur préparation consiste dans la fermentation continuée presque jusqu’ à la putréfaction de toutes les parties de la plante, la racine exceptée; par conséquent, dans un développement de tous leurs principes, dans une nouvelle combinaison et arrangement de ces mêmes principes, d’où il résulte un assemblage de particules infiniment déliées, qui, appliquées sur un sujet quelconque, y *réfléchissent* la lumière bien différemment de ce qu’ elles feroient, si ces mêmes particules étoient encore jointes à celles que la fermentation en a séparées.”

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they seem rather to have yielded to the authority of Sir Isaac Newton, and other theorists, than to have appealed to the operations of their own art, from which the real cause and origin of colours is obviously deducible.

The Art of Dying consists, principally, in covering white substances, from which light is strongly reflected, with Transparent Coloured Media, which, according to their several colours, transmit, more or less copiously, the several rays reflected from the white substances.

The Transparent Coloured Media themselves reflect no light: and it is evident that, if they yielded their colours by reflecting, instead of transmitting, the rays, the whiteness, or colour of the ground on which they are applied, would not anywise alter, or affect, the colours which they exhibit.

Such an erroneous conception of the principles of the art, cannot fail greatly to obstruct its progress, and improvement. All colouring matter is black, when viewed by incident light, and all substances incline to blackness, in proportion as they are copiously stored with tinging particles.

The Artist therefore, who confines his inquiries to substances which reflect the light, cannot be successful in his endeavours to discover new dying materials: and, if he is led, by experience, to extend his researches to other substances, his practice contradicts his principles; by which his views
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are obscured, and bounded within the narrow limits of accidental observation.

The knowledge of the optical properties of colouring matters, is also essentially requisite to their due preparation and use. As the practice of Dying, in its present state, is not regulated by any scientific rules, it is seldom improved by the introduction of new processes: and the methods of varying the uses of the materials, which are already known, are rarely ascertained without repeated trials.

All the operations of the art, excepting only a few which have arisen from accidental discoveries, owe their origin to remote ages.

We learn from the testimony of the sacred writers, as well as of the later historians, that the Indians, Egyptians, Phœnicians, and other ancient nations, excelled in the art of Dying. From the accounts, which are delivered down to us, of the colouring materials which they used, and of the clothes which were dyed with them, we find evident proofs, that they were acquainted with the principles, as well as the practice, of the art.

The ancients did not attribute a reflective power to the colouring matter; but held, that the dyed clothes reflected less light, in proportion as they were more copiously stored with tinging particles. They estimated the richness and intenseness of the dye, by its approach to blackness.

Pliny, who has recorded many curious circumstances relative to the arts, describes indigo, when undiluted,

undiluted, as a *black* substance.* The same author informs us, that the species of Tyrian dye, which was most esteemed, was of a rose colour *inclining to black*;† and that the red was inferior to that which was blacker.‡ He accurately distinguishes the bright red colour, which is transmitted through the dyed clothes, from the dark hue, which they exhibit when viewed by incident light. ||

The inattention of later philosophers, and artists, to the reflective, and transmissive, qualities of the constituent parts of Coloured Substances, has, doubtless, impeded the progress and improvement

* Plinii, L. XXXV. C. 6. Ab hoc maxima autoritas Indico. Ex India venit harundinum spumæ adhærescente limo. Cum teritur *nigrum*. At in diluendo mixturam purpuræ cæruleique mirabilem reddit.

† Ib. L. IX. C. 36. Purpuræ florem illum tingendis vestibus expetitur, in mediis habent faucibus. Liquoris hic est minimi in candida vena, unde pretiosus ille bibitur *nigrantis* rosæ colore subluens.

‡ Ib. L. IX. C. 38. Rubens color *nigrante* deterior.

|| Ib. L. IX. C. 38. Laus ei summa; color sanguinis concreti, *nigricans aspectu*, idemque *suspectu resurgens*.

It appears from the following passage, cited from Macrobius, that the dealers in dyed clothes were accustomed to consider the colours; which they yielded by transmission, as well as those which they afforded, when viewed by incident light. "Cum de Tyriæ purpuræ, quam emi jusserrat, obscuritate quereretur (Augustus) dicente venditore, erige altius et suspice, his salibus usus est: Quid? ergo ut me populus Romanus dicat bene cultum, in solario ambulaturus sum?" Macrobius. Lib. II. Saturn.

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of the science of Optics, and of the arts which are dependent upon it. This experimental research was undertaken, for the purpose of examining the optical qualities of such substances.

During the course of my inquiry, I have observed, that the transition from physical experiments, to practical operations of dying, is easy and obvious. For, the experiments, which I have made, with a view of investigating the origin and cause of colours, have guided me to the discovery of several bright and permanent dyes, in the execution of which I have, principally, used cheap and common ingredients, that have not before been applied to such purposes.

I do not doubt, that a clear, and comprehensive, view of the principles of the art will open, to the artists who practise it, a fertile source, from which, with certainty and facility, they may derive the discovery of new materials, and of the most advantageous means of employing them.

The art of Painting, also, will receive great advantage, from an accurate and precise conception of the principles, by means of which the matters, endued with a reflective power, may be distinguished from others which transmit the rays, but do not reflect them.

The works of many Painters greatly excel in the clearness and brightness of their colouring : *
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* Several of the greatest masters practised a method of colouring, which was, in some respects, conformable to the
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but, it is unquestionable that a scientific knowledge of the nature of the colours, which they used, would have enabled even the greatest masters to have communicated, to those works, a still higher degree of excellence.

I shall not regret the labours which I have bestowed on the subject of these pages, if they contribute to the advancement of those useful and elegant arts, which are of much importance to a commercial nation; or if, by the disclosure of physical truths, they extend the bounds of science, or open new paths to its improvement.

the true principles of Optics, and of their art. One of our most eminent Painters has observed, from a minute and accurate examination of some of the most capital pictures of Titian, Tintoret, Paul Veronese, and other Italian, Flemish, and Dutch masters, that they painted with transparent colours, upon a white ground. This practice was carried to the highest degree of perfection by Correggio. That great colourist grounded his pictures with black and white only: and by the delicacy, clearness, and brilliancy of the transparent colours, which he laid on the grounds thus prepared, he gave to his compositions a peculiar force and relief, and a near resemblance of nature. Few modern artists have been able to comprehend the means, by which those effects were produced. Leonardo Da Vinci, in his instructive Treatise of Painting, recommends the use of white grounds, and transparent colours, as the true method of procuring the most brilliant colouring. Cap. 100. "*Sempre à quelli colori, che vuoi che habbino bellezza, prepararai prima il campo candidissimo, e questo dico de' colori che sono trasparenti, perche a quelli che non sono trasparenti, non giova campo chiaro.*"



